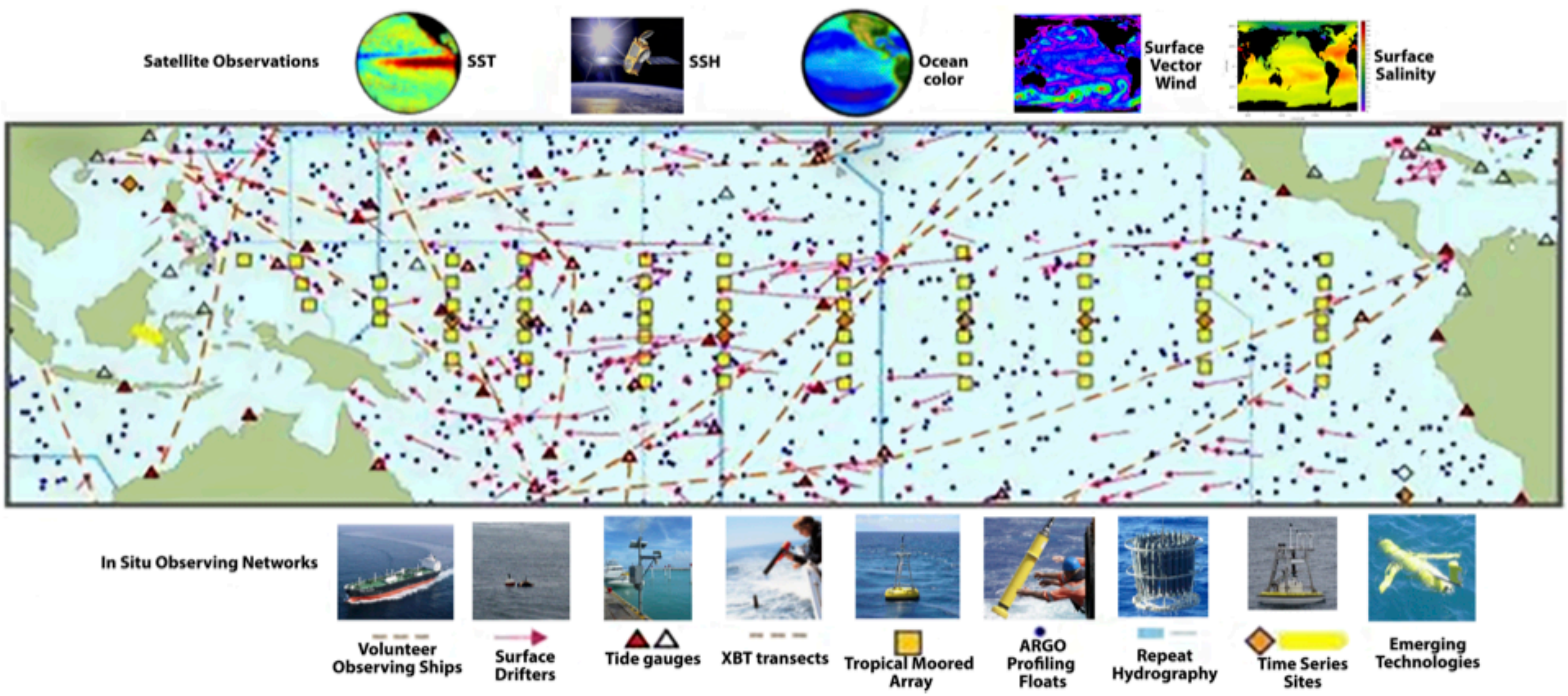
TPOS 2020 Project

Review and re-design the Tropical Pacific Observing System

- Rethink in response to new needs, purposes, challenges: Define requirements
- Renew the interagency and intergovernmental cooperation that has been the hallmark of the TPOS since the mid-1980's
- Take advantage of new science and technology



Why do we care?

- Largest source of intraseasonal to interannual predictability AND prediction
  - Requires both good observations and good models
- Largest natural ocean source of CO_2 outgassing
  - Strong annual, interannual and lower-frequency variability. A major part of the global carbon budget
- Sensitivity of the entire climate system to changes in the tropical Pacific
  - ENSO signals reverberate globally

ENSO drove the original T.P.O.S.

- El Niño of 1982-83

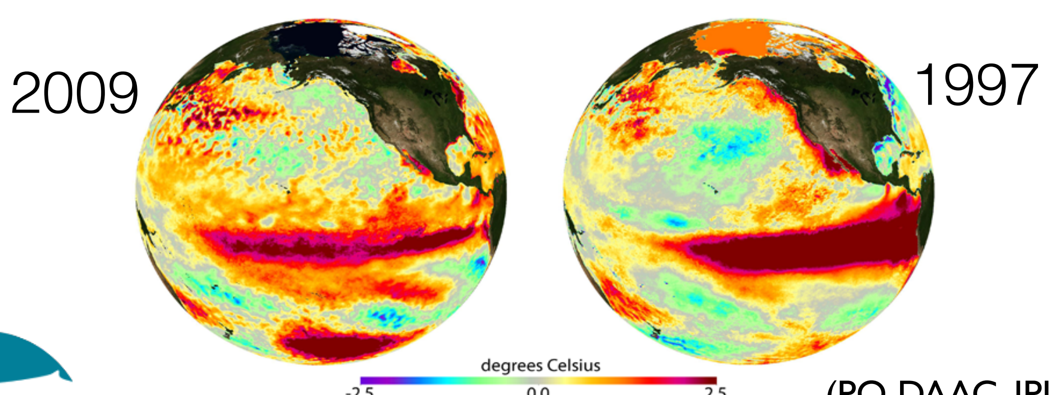
  – and the failure to recognize it until very late – was the impetus for the TOGA observing system.

- Original TAO designed as a grid for mapping purposes,

  at a time when most ocean time series were sampled from merchant ships.

- Now, we have many technologies, and we face a different set of challenges. We aim to adapt the observing and forecast systems to today's issues.

The lesson of the past 3 decades is ENSO diversity, the ongoing succession of surprises in these events. The potential for future surprises is high.



(PO DAAC, JPL)

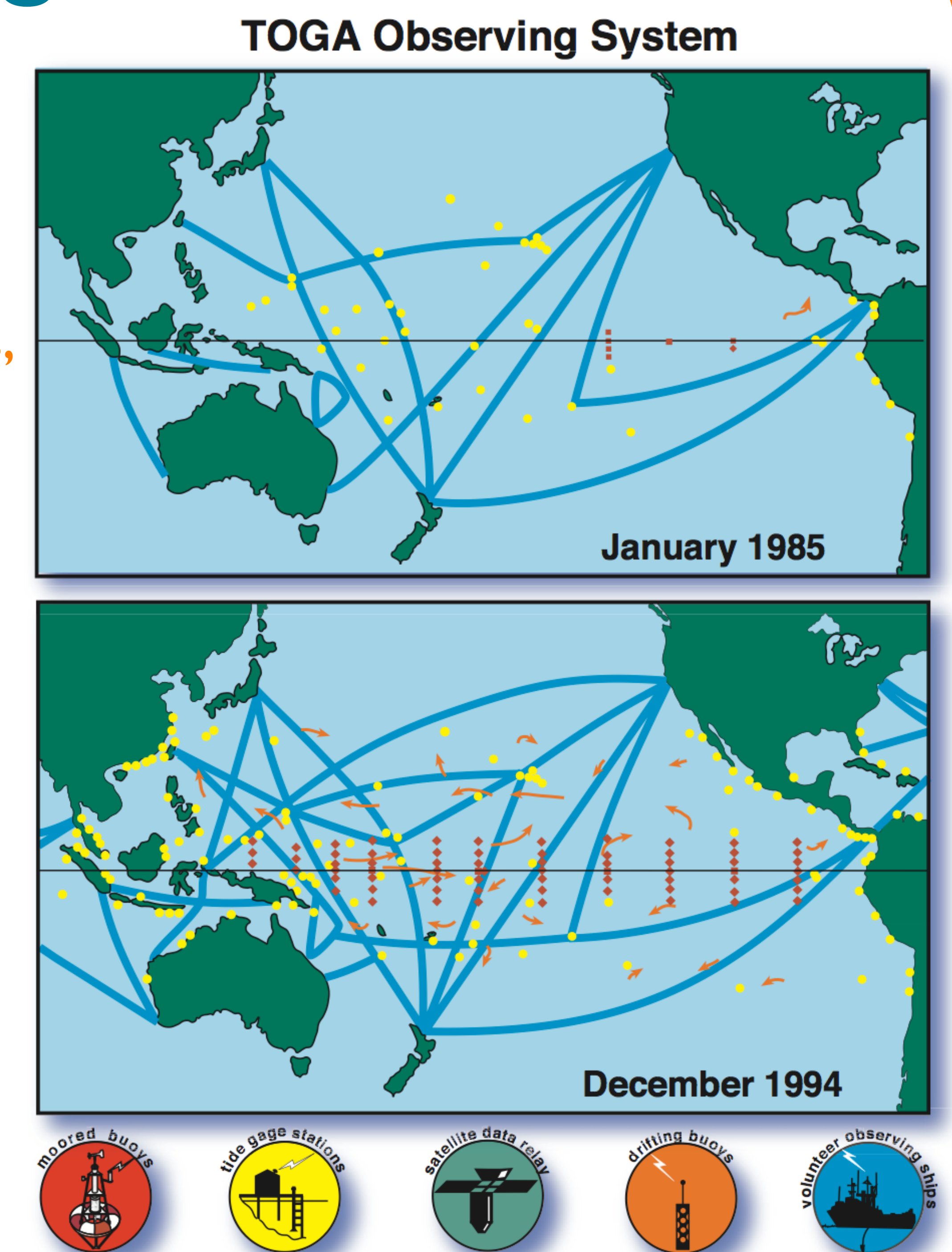


Figure 2. In situ components of the Tropical Ocean Global Atmosphere (TOGA) observing system at (top) the start of TOGA in January 1985 and (bottom) the end of TOGA in December 1994. Color coding indicates the moorings (red symbols), drifting buoys (orange arrows, one for approximately every 10 drifters), ship-of-opportunity lines (blue), and tide gauges (yellow). *After McPhaden et al., 1998*

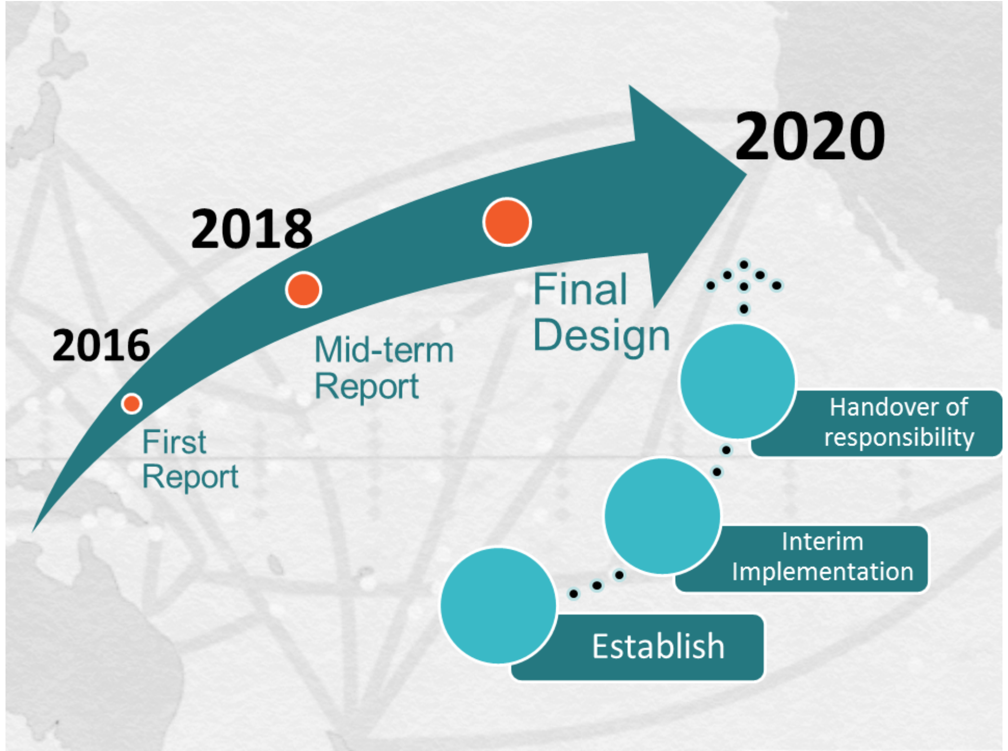
Foundation of the T.P.O.S.

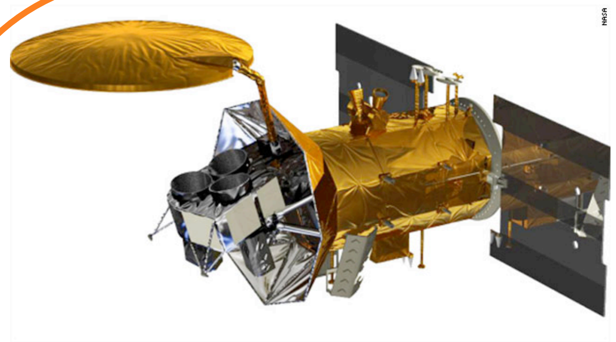
Technical and intellectual advances of the 1980s-2000s

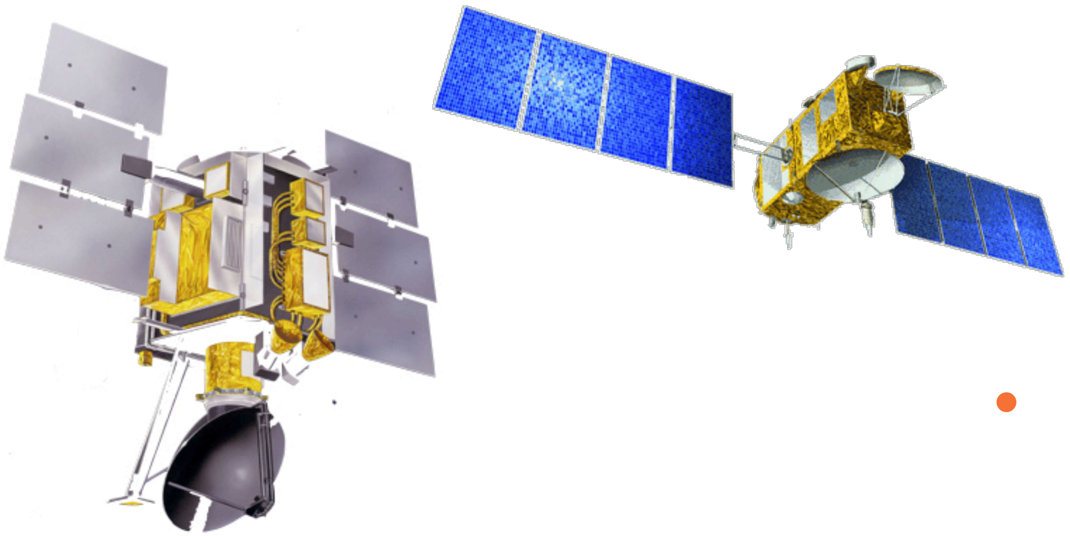
- Advances during the TOGA program (1985-94)
  - Many nations cooperated to build a realtime tropical monitoring array
  - New theories showed the predictability due to ocean memory
  - Early coupled models began to take advantage and make predictions
  - Simple moorings, mass-produced, realtime data (TAO, then TRITON)
- Satellite era – beyond SST – began in the early 1990s
  - Vector winds, SSH, ocean color, ..., and remote SST sampling also advanced
- Argo profiling floats in the early 2000s
  - Consistent global mapping of subsurface temperature and salinity

TPOS 2020 Goals

- To redesign and refine the T.P.O.S. to observe ENSO and advance understanding of its causes
- To determine the most efficient and effective observational solutions to support prediction systems for ocean, weather and climate services
- To advance understanding of tropical Pacific physical and biogeochemical variability and predictability.





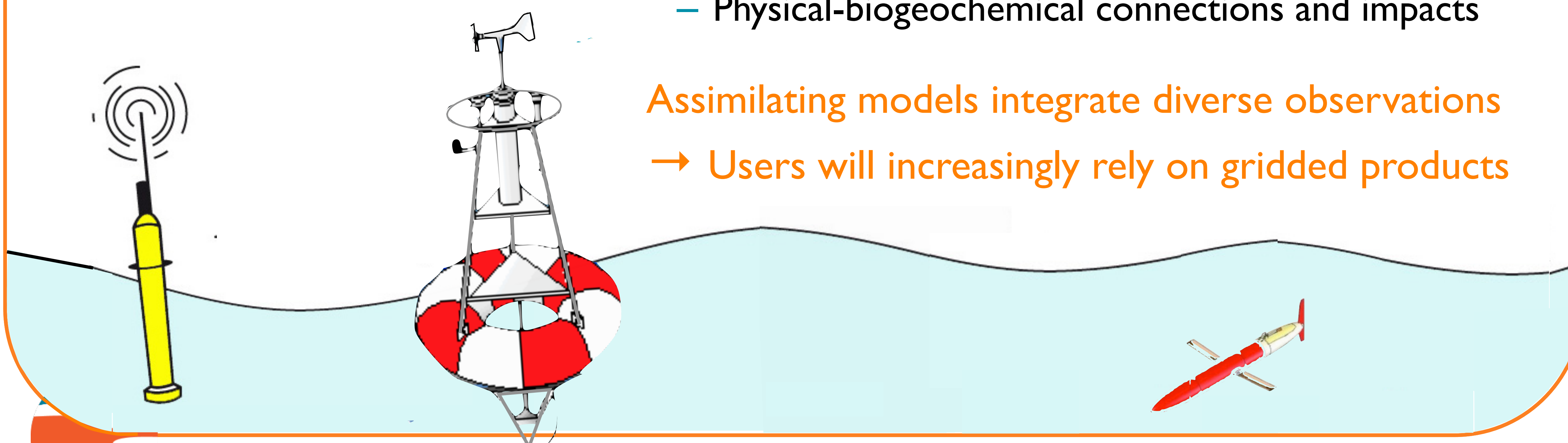


An integrated view

- Complementary "backbone" technologies:
  - Satellites give global coverage, fine spatial detail in (x,y)
  - Moorings sample across timescales, allow co-located ocean-atmosphere observations, velocity sampling
  - Argo resolves fine vertical structure, adds salinity, maps subsurface T and S and connects to subtropics
- New scientific understanding and issues:
  - Role of high-frequencies, especially the diurnal cycle
  - Focus on the coupled boundary layers
  - Physical-biogeochemical connections and impacts

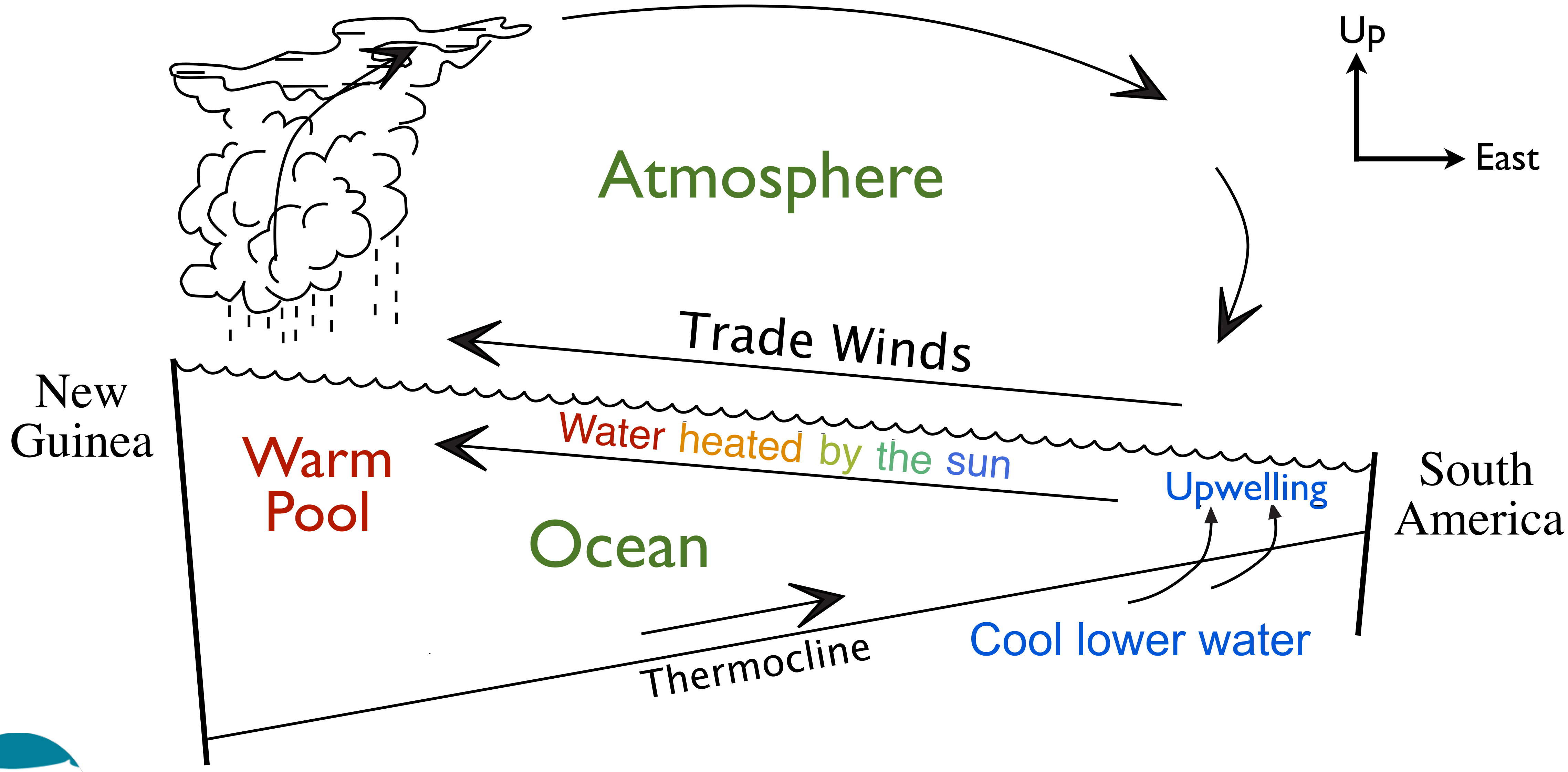
Assimilating models integrate diverse observations

→ Users will increasingly rely on gridded products



Fundamental processes

The special dynamics of the tropics produce tight ocean-atmosphere coupling and feedbacks



TPOS 2020 vs other developing observing systems

- The tropical Pacific has a dominant signal: ENSO

  → We are strongly driven by phenomena

- In large part due to ENSO,

  the history of successful seasonal forecasts means we have important operational stakeholders.

- The fundamental coupled nature of the tropical climate

  means the planetary boundary layer is a core part of our sampling (dictates platform requirements)

It’s not just El Niño …

Because the atmosphere is so sensitive to changes tropical heating, many kinds of tropical disturbances radiate to mid-latitudes.

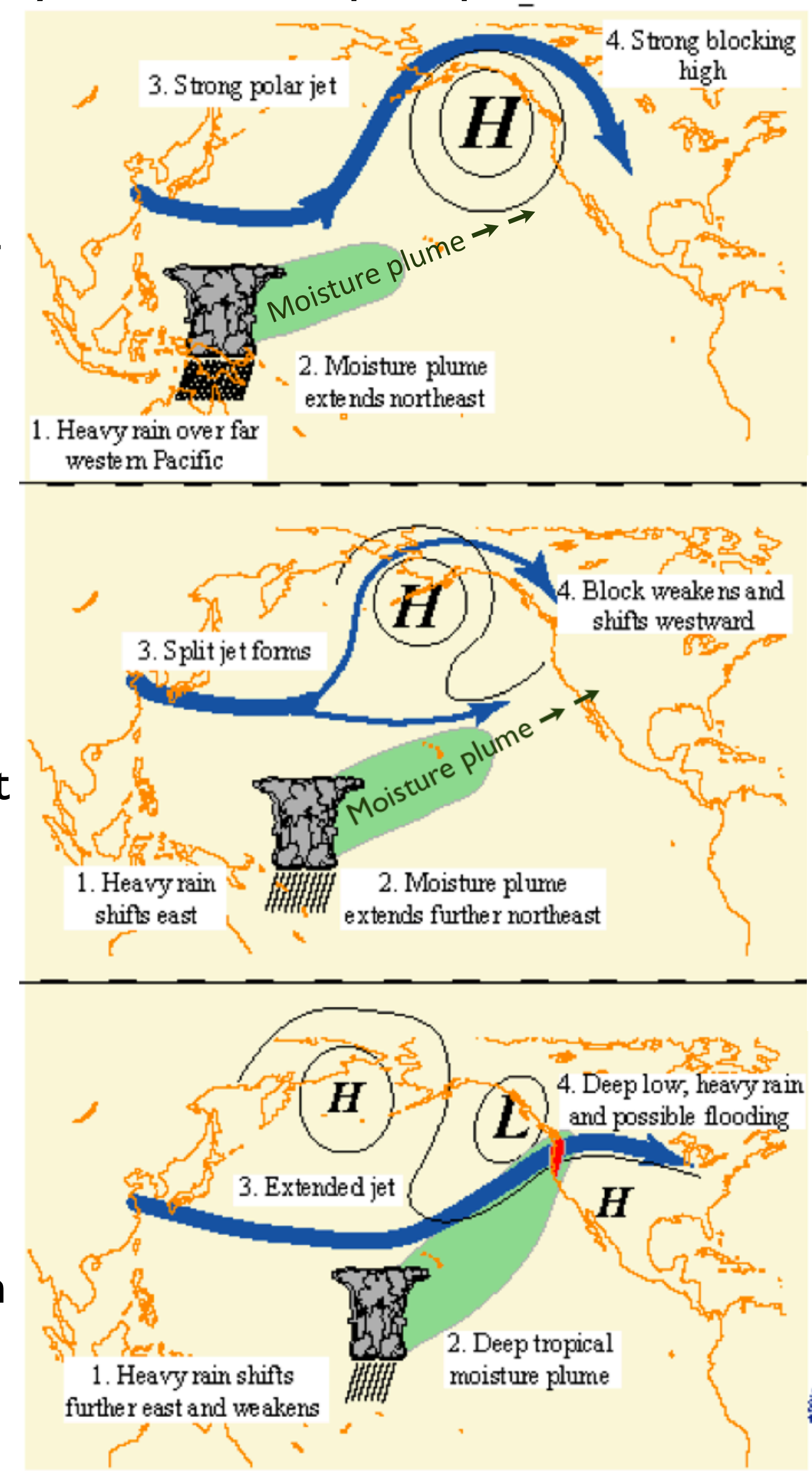
An example is the MJO, that powers intraseasonal heavy rain events on the US west coast (“Pineapple Express”).

Winter tropical Pacific anomalies preceding heavy West Coast precipitation events

7-10 days before event

3-5 days before event

Precipitation event



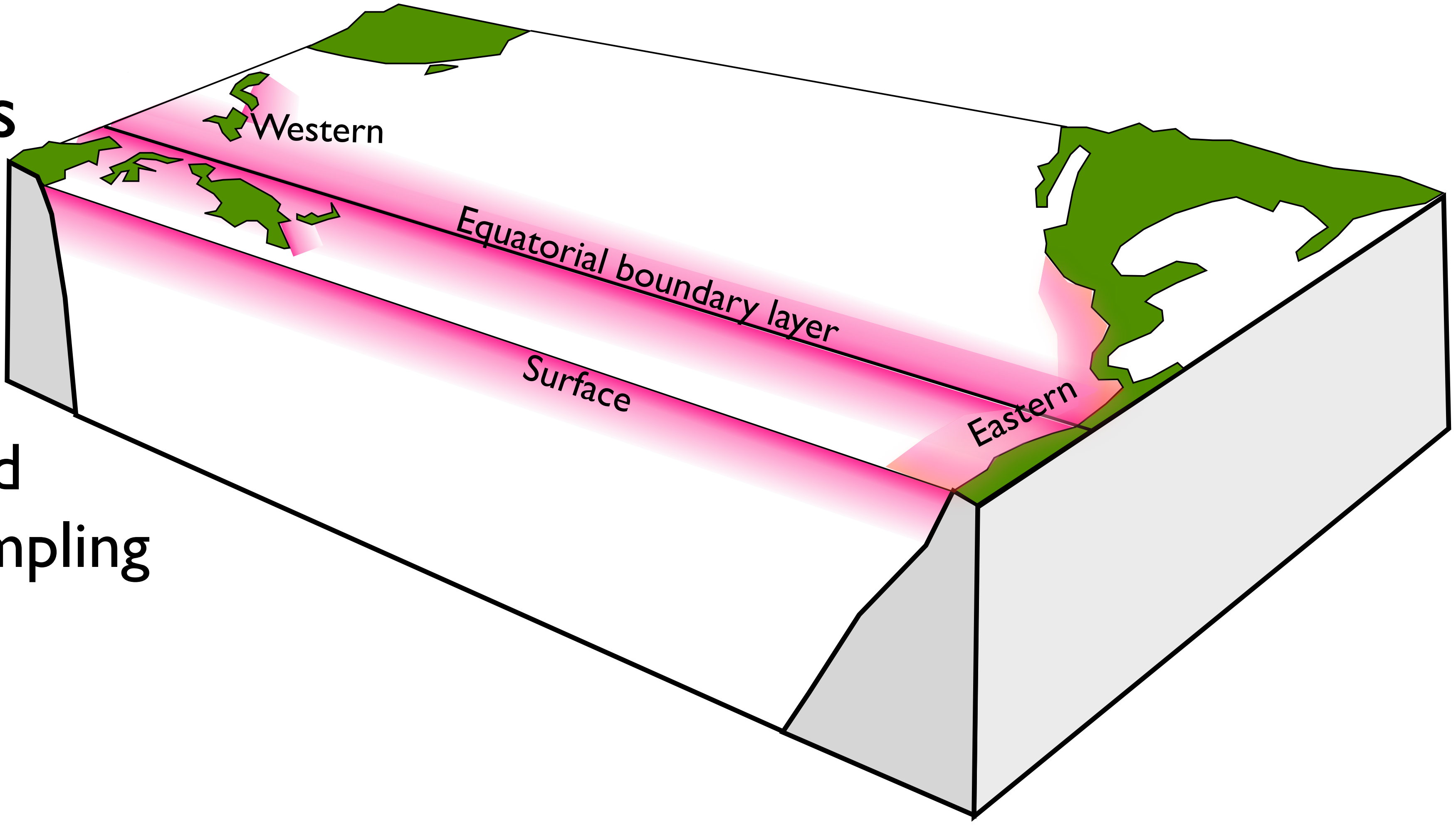
Climate Prediction Center/NCEP/NWS

We view the tropical Pacific as consisting of a broad interior plus four “boundary layers”:

Surface, Equatorial, Eastern and Western

The boundary layers are the hard parts

In an integrated system that includes satellites, we are less tied to a grid and can focus in situ sampling on key regimes.



Surface boundary layer

How does the thermocline communicate with the atmosphere?

The diurnal cycle is surprisingly important …
Can we teach this to models?

Diurnal cycle composite at 2°N,140°W: Winds, current shear.

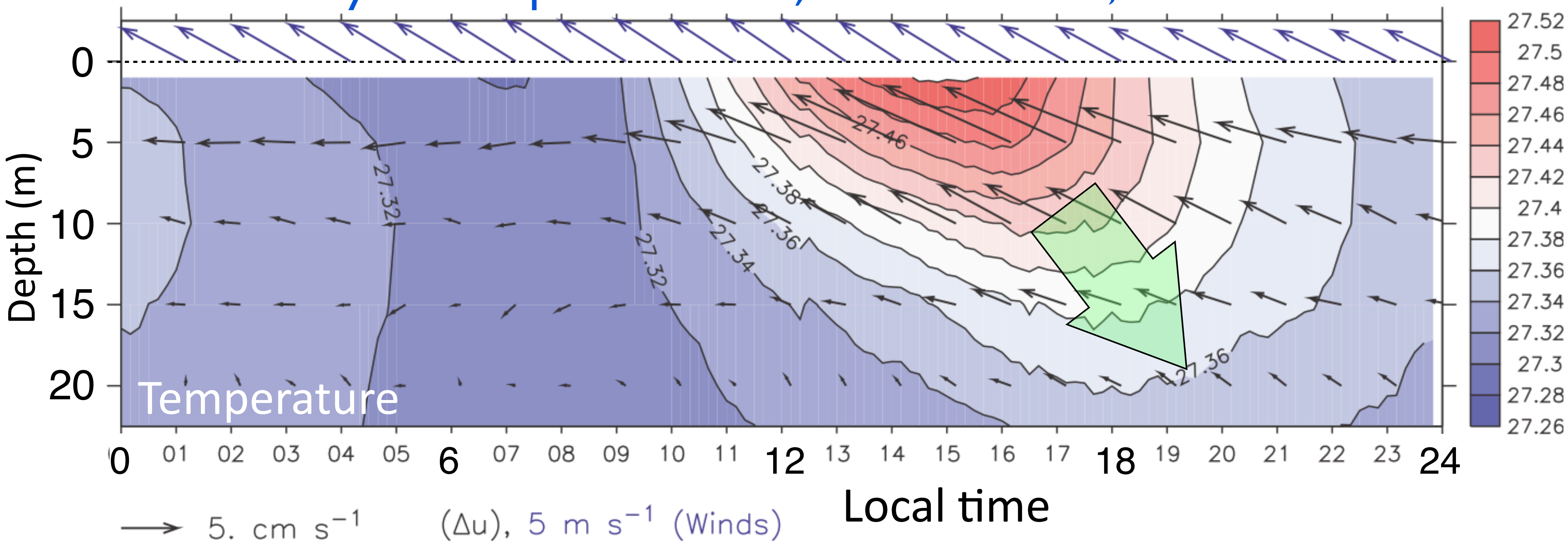


FIG. 5. Mean diurnal composite (24 May 2004–7 Oct 2004) of wind (blue vectors), temperature (color shading), and currents relative to 25 m (black vectors). The vector scale is shown at the bottom. Cronin and Kessler (2009)

Much of the work of heat and momentum transmission to the thermocline is accomplished by the diurnal cycle. ⇨ Requirement to observe the near-surface, including currents … but how much is needed?

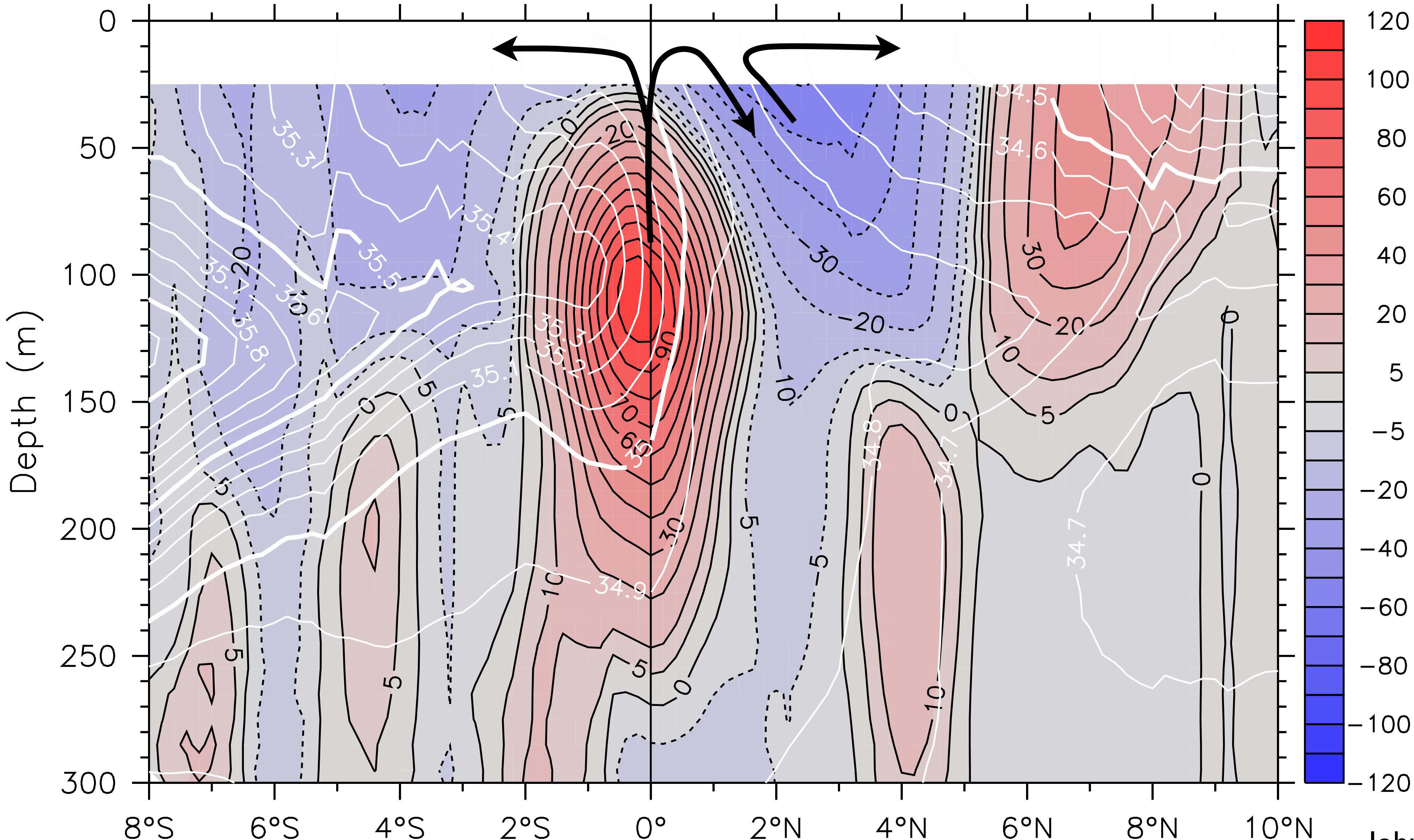
Equatorial boundary layer

Short meridional scales, property emergence (heat, CO_2)

Rapid and vigorous air-sea coupling gives these processes global significance.

→ Demanding requirements for properties and currents

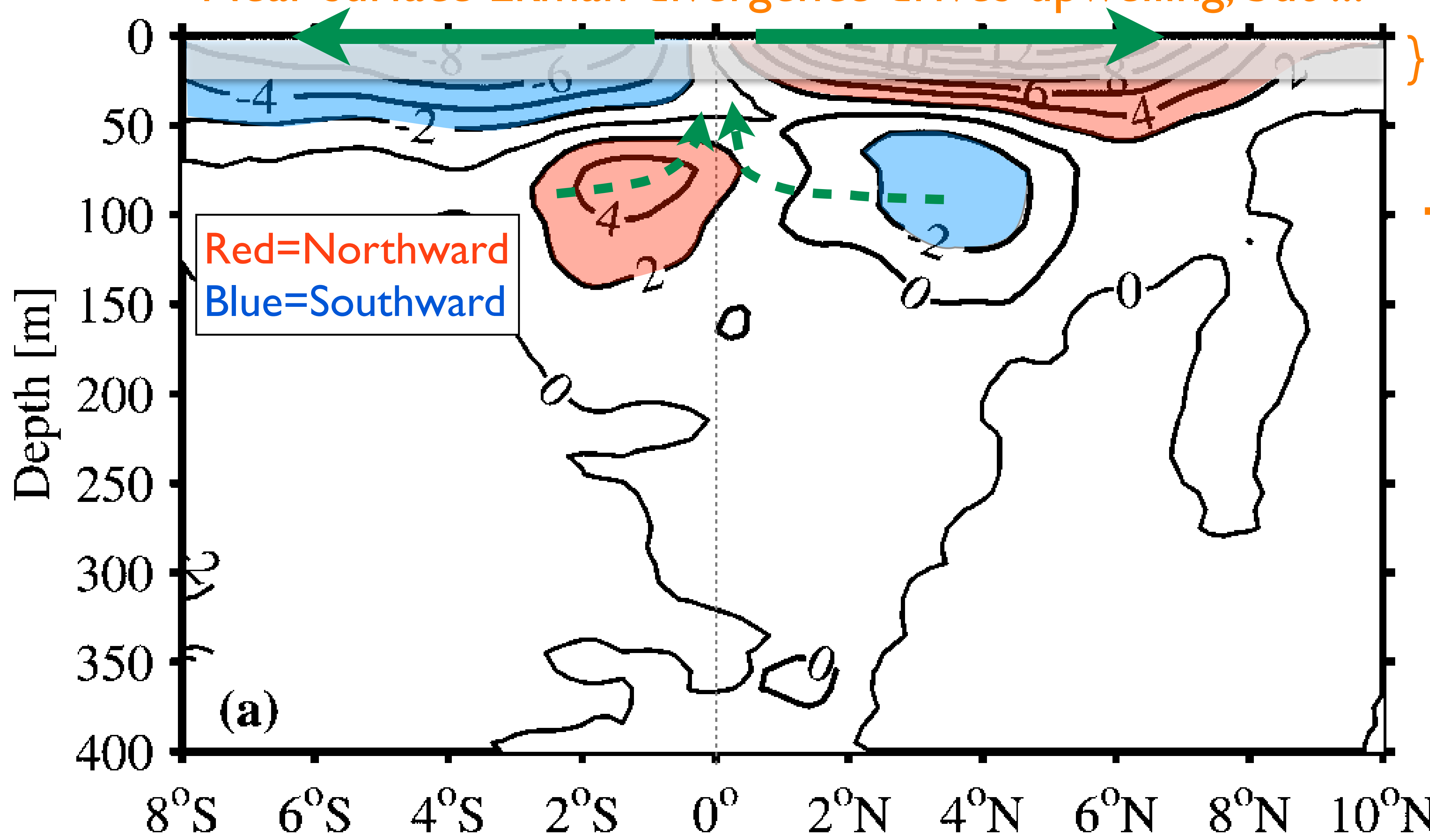
Mean zonal current (colors) and salinity (white contours) at 140°W (sketch of w)



Johnson et al. (2001)

Surface and equatorial boundary layers

Near-surface Ekman divergence drives upwelling, but ...



(Ship ADCP } does not see upper 25m)

- Requirement for near-surface currents, especially near the equator.

Another driver: Referencing scatterometer winds where currents are strong

Mean meridional current in the east-central Pacific

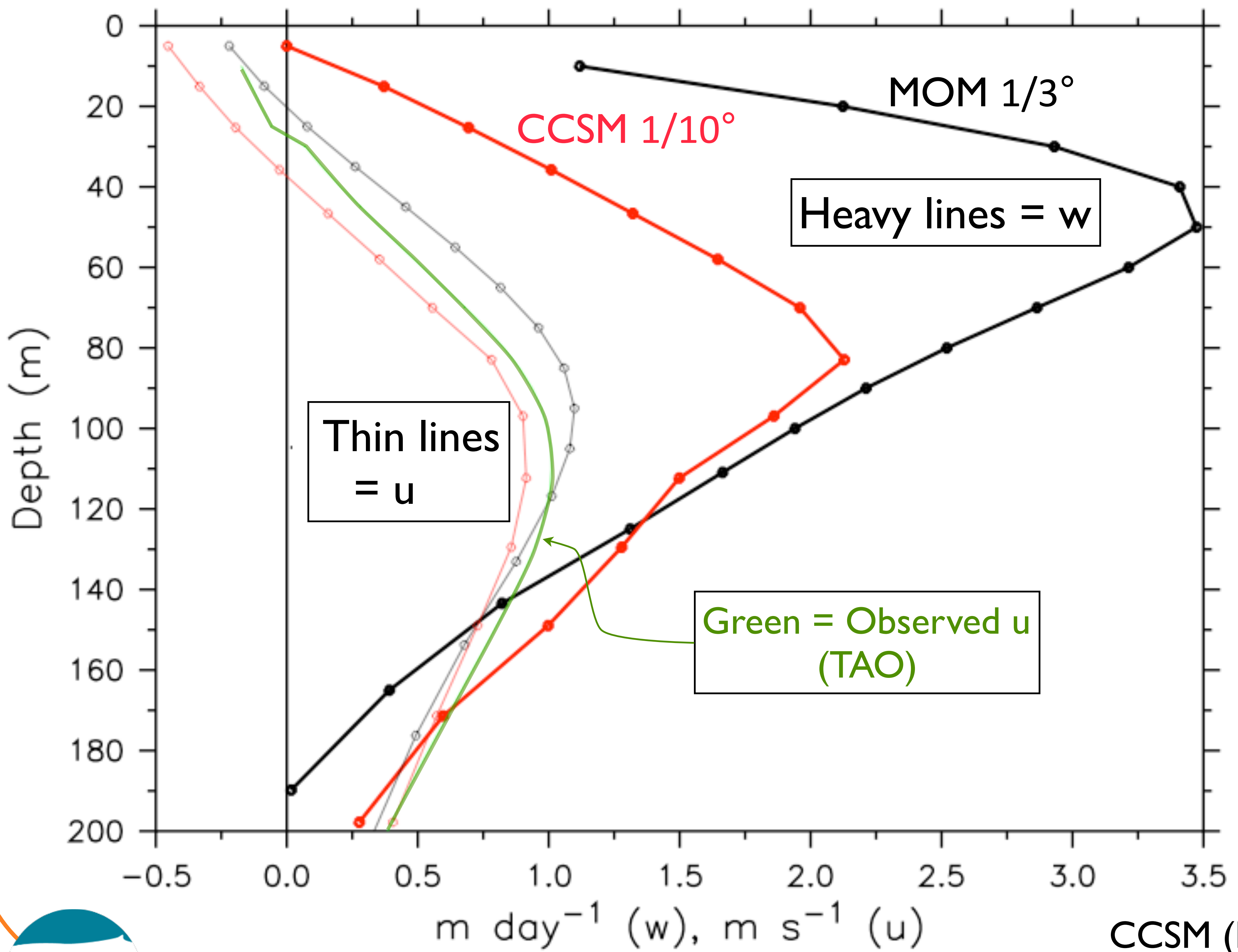
Shipboard ADCP over 170°W-95°W

10-year average

Johnson et al. (2001)

How do models represent this circulation?
(We don't know!)

Mean u and w at 0°, 140°W



The usual model-data comparisons of u(Eq,z) can be misleading.

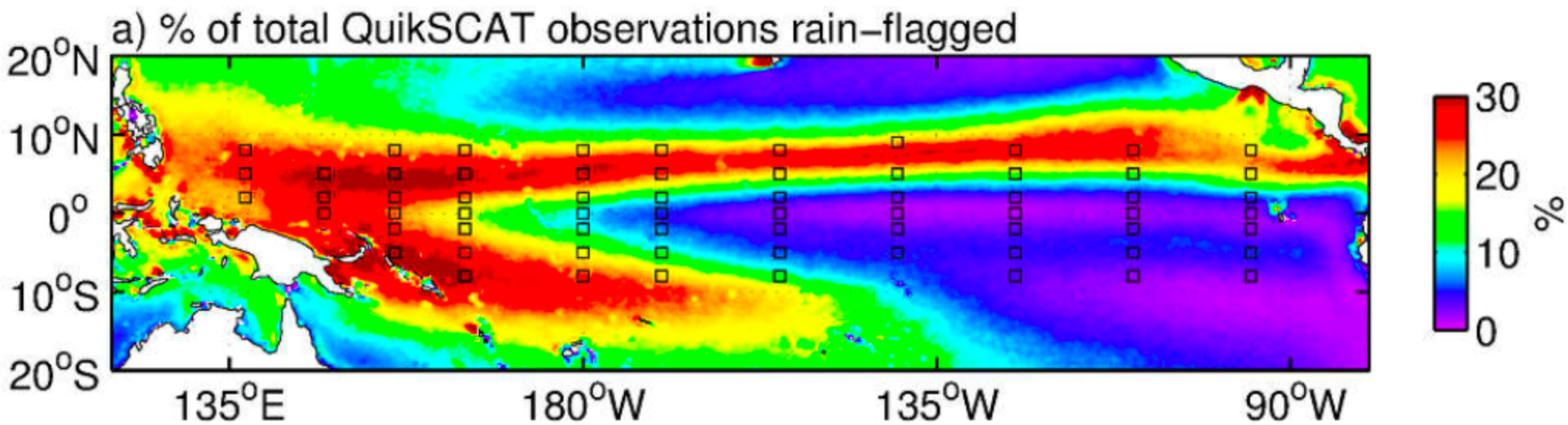
Model representations of the vertical flows are unconstrained.

CCSM (Bryan), MOM (Vecchi)

Requirements for the backbone

What drives our recommendations?

Example: Vector winds



QuikSCAT rain-flag frequency during 1999-2009.
Over much of the Pacific ~25% of QuikSCAT samples are flagged as <u>potentially</u> invalid due to rain.

This does not mean that scatterometer winds are unusable under rain, but they are in question. It is also true that wind <u>products</u> from different centers differ significantly.

The global climate is exquisitely sensitive to the equatorial zonal wind, so we must get this right.

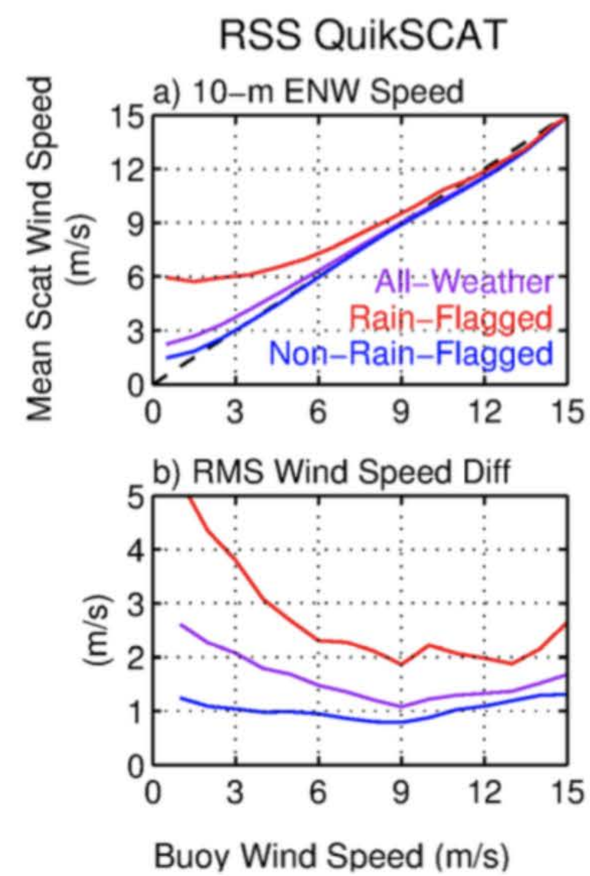
Winds with a reduced moored array

TAO was originally designed to map winds, before scatterometry.

Now we propose to reduce buoy locations, relying more on scatterometer winds.

Two distinct issues:

1) How well do scatterometers measure winds themselves?
2) How well do present analyses produce credible wind fields?



We investigated (1) extensively:

- Only a few ongoing cal/val points are needed in the tropics
- Specific regions need in situ referencing (heavy rain / low winds)
- Equator needs referencing between satellite generations

These considerations were influential in shaping our design:

In situ wind sampling in heavy rain regimes: ITCZ, SPCZ, Warm pool

Maintain full sampling along the equator

The mapping issues (2) are more difficult:
Products from different centers differ considerably! Work is needed!

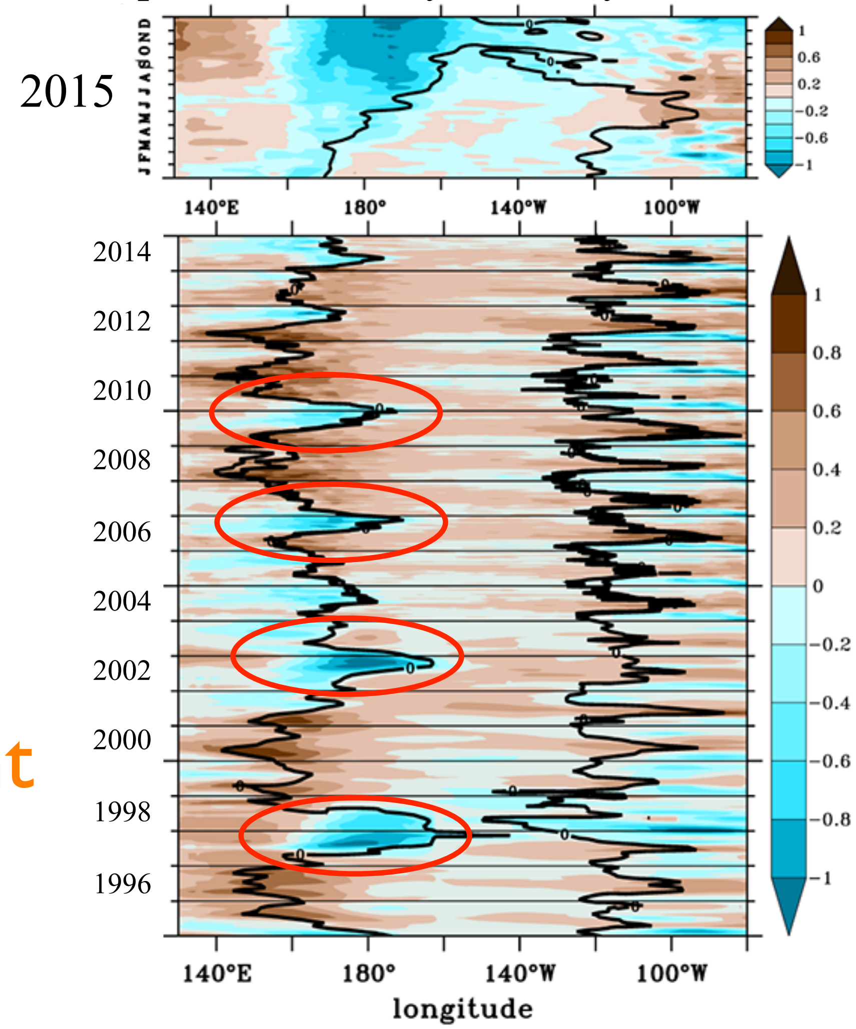
→ TPOS 2020 must provide the in situ observations for adequate referencing of scatterometer winds

The West Pacific Warm Pool
Salinity is crucial

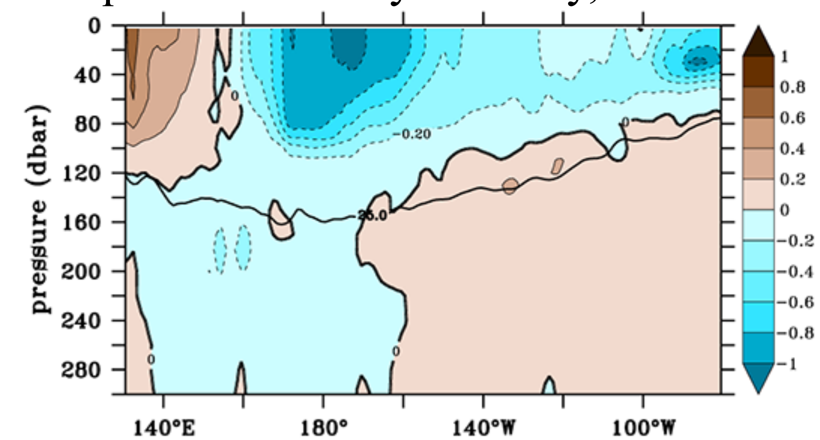
Under the heavy rain of the warm pool, salinity variability is a large part of the pressure gradient. It is strongly tied to ENSO.

Drives our requirement for subsurface salinity observation.

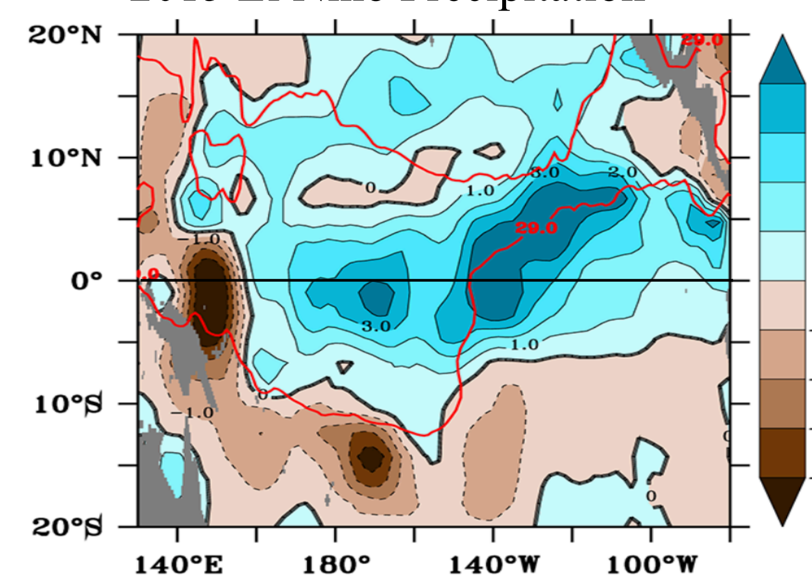
Equatorial salinity anomaly time series



Equatorial salinity anomaly, Dec 2015



2015 El Niño Precipitation



(Gasparin and Roemmich 2016)

The First Report

- Published 30 December 2016 (ref. GCOS-200)
- 22 Recommendations
- 15 Actions

} Neville's talk to follow

- First published design following the GOOS Framework
- 2 rounds of review and revision

tpos2020.org/first-report

(much of this applies to the other tropical oceans!)

Our first customers are the operational centers

Although TPOS 2020 is mostly about observations,
we consider the role of observations in the entire system:

Observations • Analyses • Forecasts

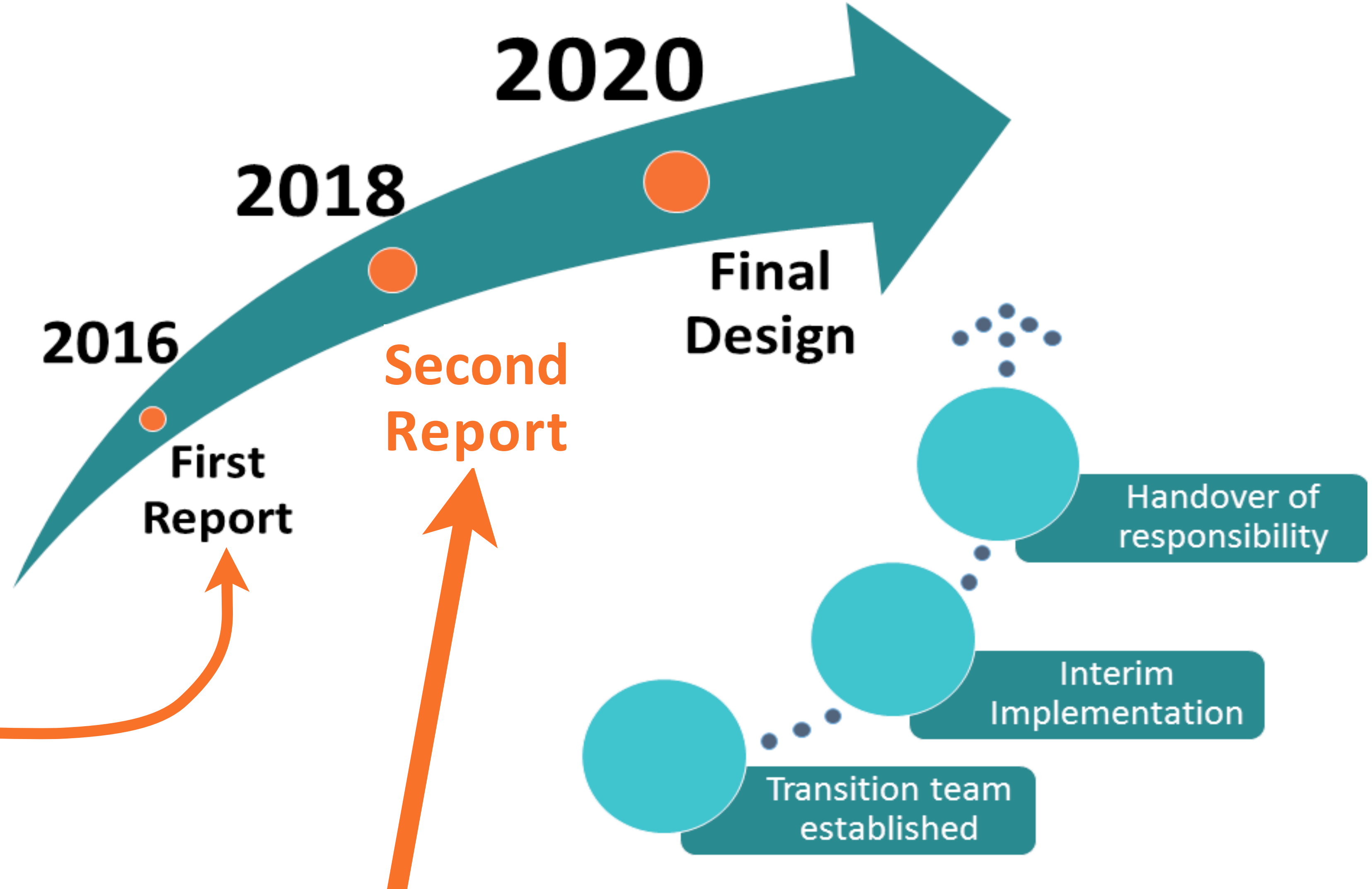
Current-generation assimilation/forecast systems do not make effective-enough use of observations.

Thus we aim to:

- → Target sampling where the models and data assimilation systems need guidance for improvements (near-surface and near-equator)
- → Improve model representation of unresolved processes
- → Evolve the T.P.O.S. in concert with advances in the forecast and data assimilation systems
- → The operational "backbone" array must provide infrastructure for research to improve the models, and refine the design

We design our arrays to serve both operations and research

Next steps

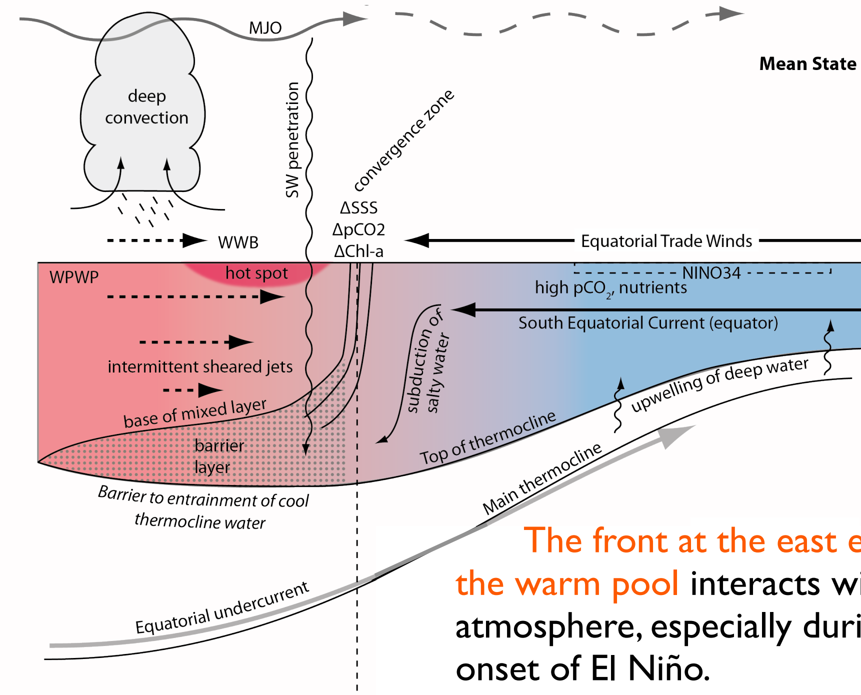


Second report foci:

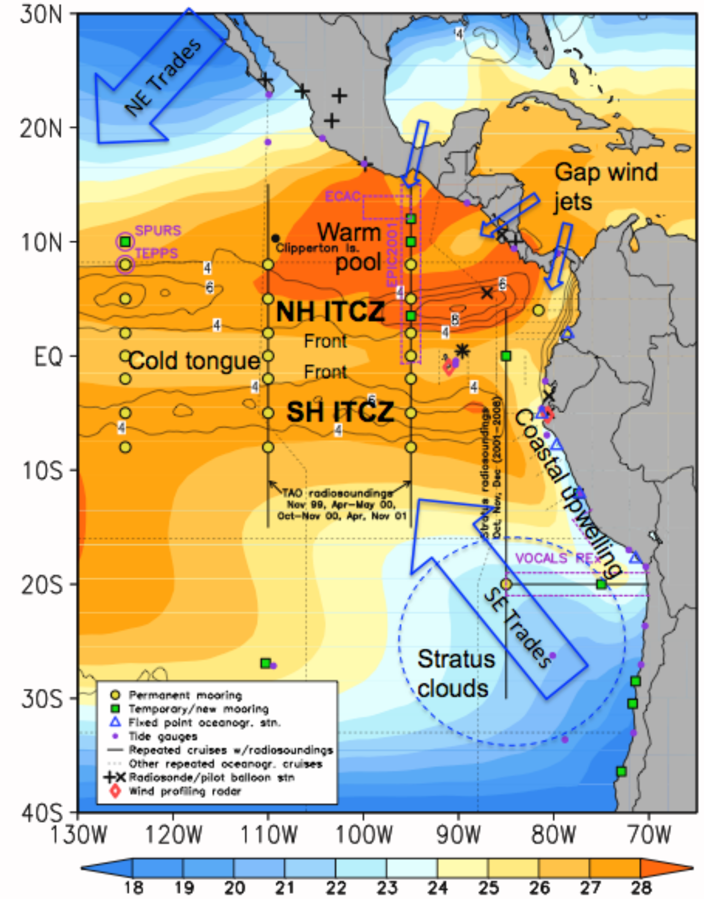
- Improving modelling and data assimilation
- Biogeochemical and ecosystem observations (Beyond pCO_2, what?)

Advance: Research required!

- Pilot studies enhance TPOS capability
- Process studies to understand phenomena
- Modeling studies add value to observations, assess their impact

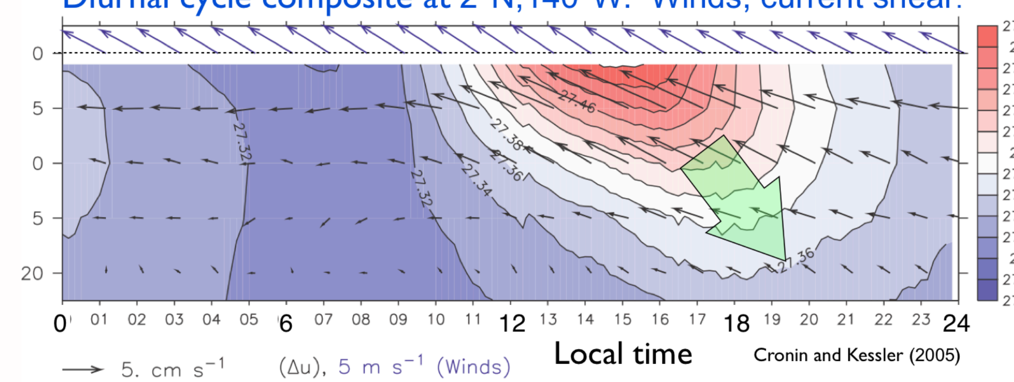


The front at the east edge of the warm pool interacts with the atmosphere, especially during the onset of El Niño.

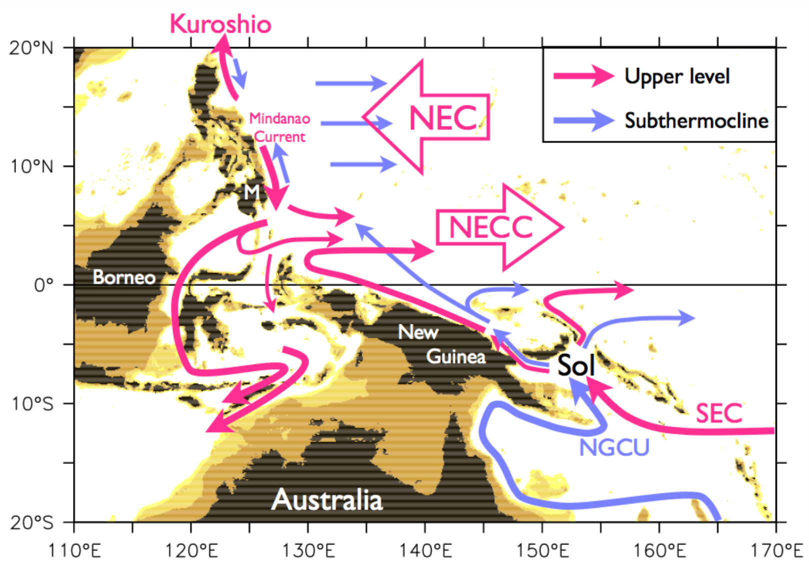


Critical processes in the east include the stratus/cold tongue front/ITCZ system and coastal upwelling.

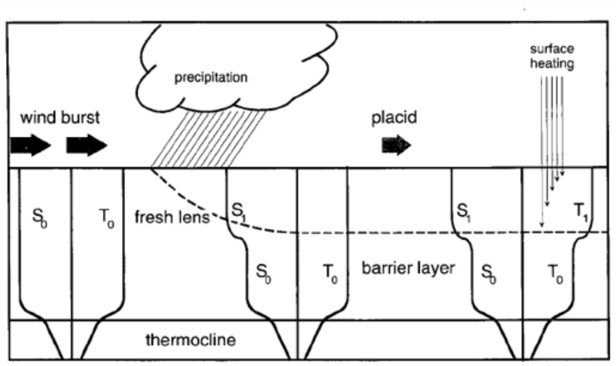
Diurnal cycle composite at 2°N,140°W: Winds, current shear.



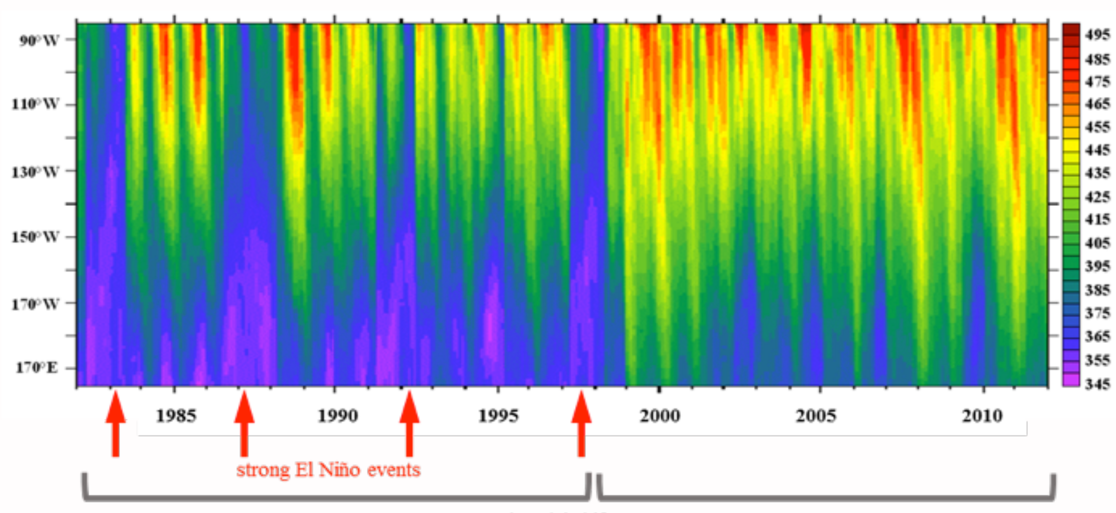
The diurnal cycle can be an important mechanism allowing downward propagation of heat and momentum fluxes.



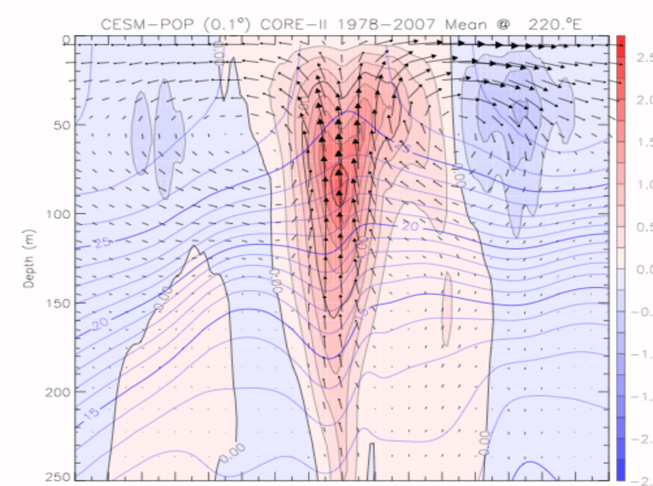
Low-latitude western boundary currents and the Indonesian Throughflow are principal conduits of tropical-subtropical interaction.



Barrier layers in the west Pacific warm pool affect the penetration of momentum fluxes.



The 30-year record of surface pCO_2 shows strong annual, interannual and decadal variability of CO2 fluxes in the east Pacific cold tongue.



Equatorial upwelling is fundamental but poorly known; its modeling is uncertain.

TPOS 2020 Tropical Pacific Observing System

Underway pilot/process studies:

Autonomous vehicles and platform enhancements

NOAA
- Autonomous surface vehicles: PBL and surface BGC
- Argo enhancements: rainfall, windspeed and BGC
- Enhanced ocean boundary layer sampling from TAO
- Direct covariance flux measurements from TAO

JAMSTEC
- Autonomous surface vehicles: surface fluxes
- Upgrade 3 TRITON sites to flux Supersites
- Shallow floats
- Research cruises

NASA
- SPURS-2 Experiment at 10°N,125°W (ITCZ)

Other pilots expected:
-Warm pool array
-Indonesian Throughflow
-Western boundary currents


Wave glider

Autonomous surface vehicles have great promise, but need testing in real-world conditions to prove their possibilities and learn their limitations.

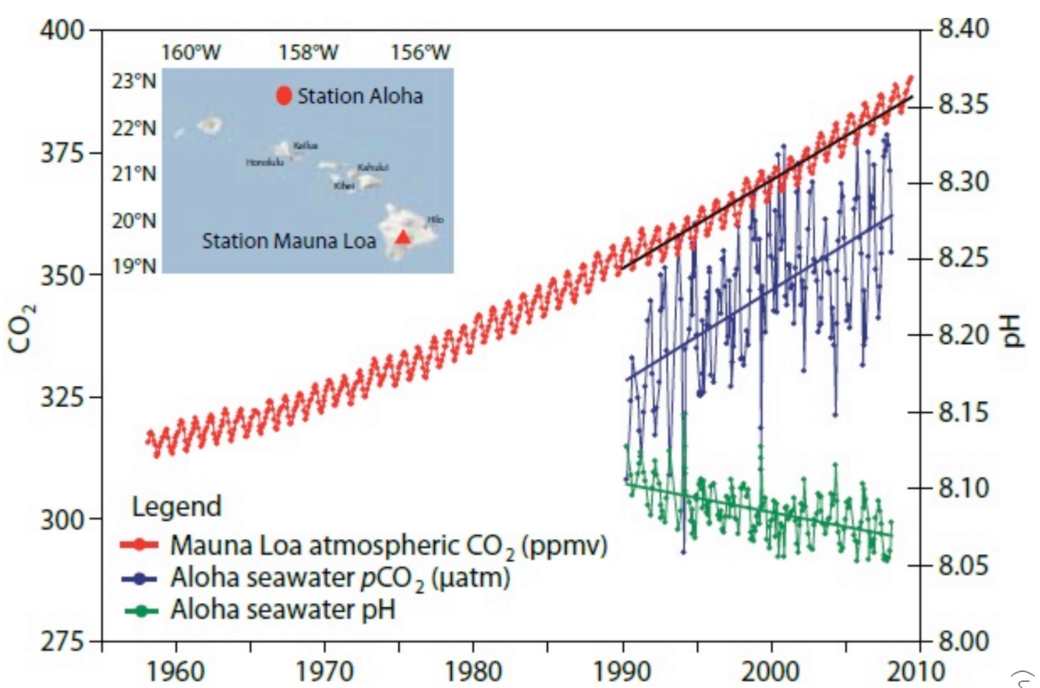
New investments will advance these technologies.

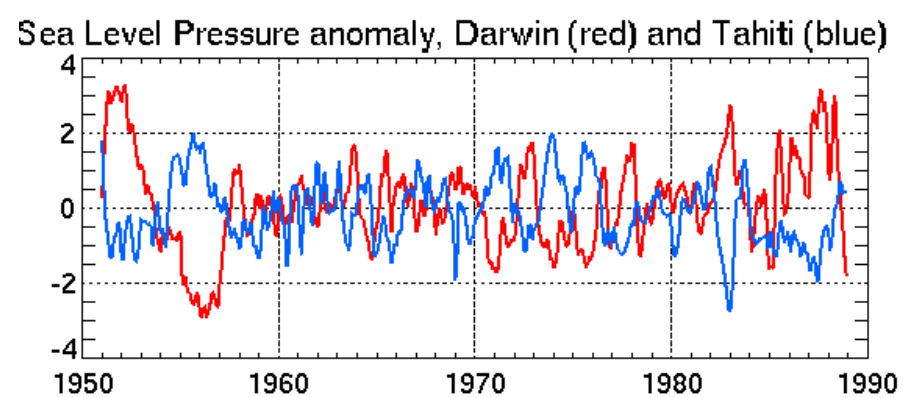

Saildrone

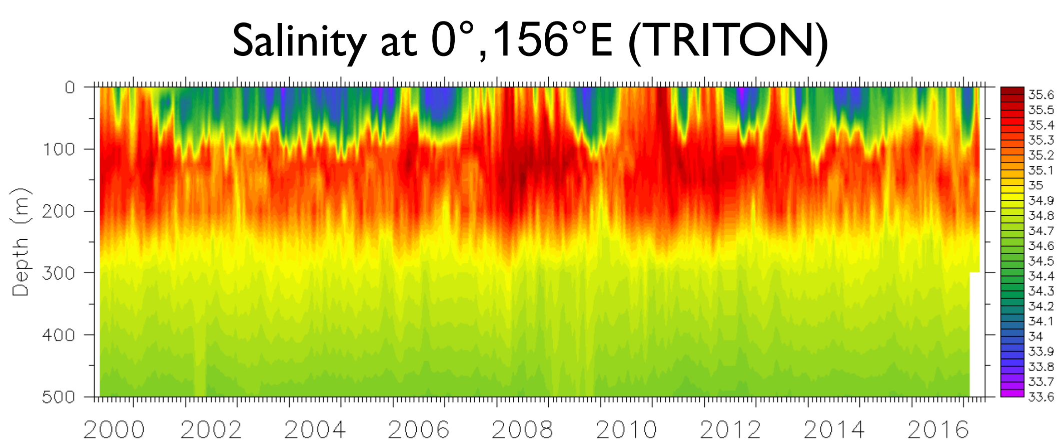
Why do we propose changes, when the tropical Pacific is not over-sampled now?

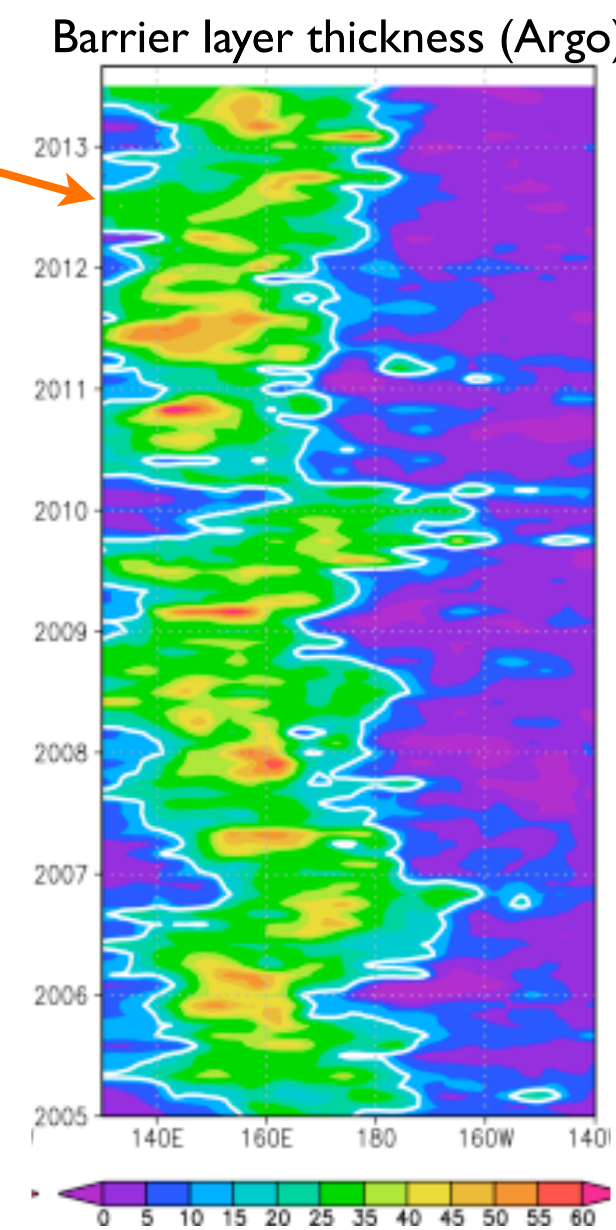
A "climate data record" is a time series at a point (examples).

A "climate record" is a set of measurements that enable detection and accurate description of an element of climate variability in its longterm context.









We must preserve the climate record

Conclude (Actions later: NRS)

- We have the tools to modernize the present system
  - Take full advantage of technology, respond to modern science issues
  - More resilient, more effective: integration across platforms
- We will live with the new design for decades
  - Identified topics where research and pilot studies are needed:

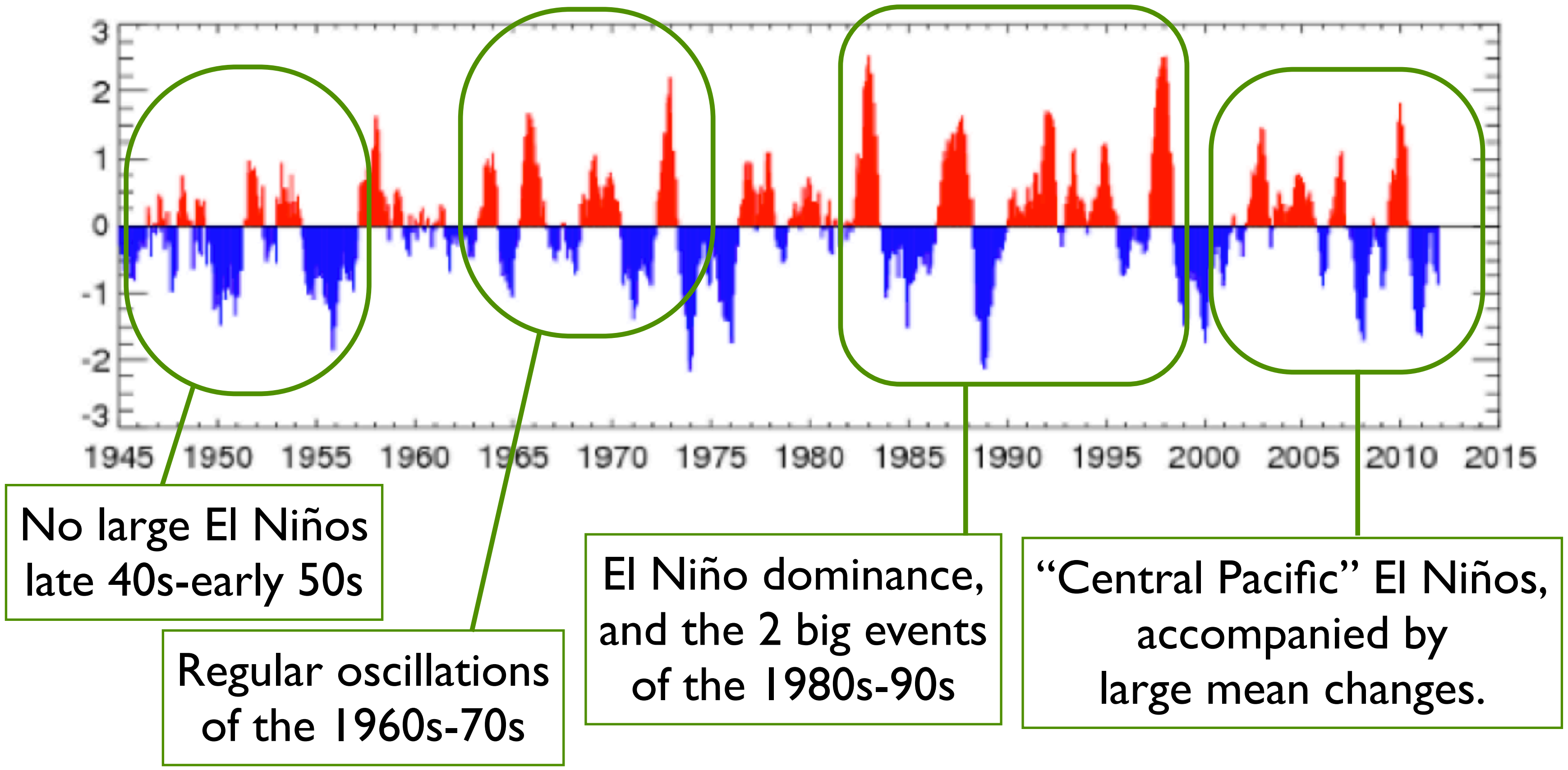
    Includes in situ, satellite, and model development
  - Must move carefully and thoughtfully: 2 years of work, broad consultation
- Neville's talk to come will explain our design

  Responds to the issues raised here

Extra slides below

ENSO is irregular ... and full of surprises

Niño 3.4 (Central Pacific) SST (red = El Niño)



- The overall story is diversity and surprises. Expect more ...
- These event changes have been accompanied by changes to the background (e.g., trade wind increase since 1998).

The lessons we take from this are:

Build a resilient T.P.O.S.

Do not focus only on the challenges/issues of today; tomorrow's will be different:
Looking back from 2030, what will we wish we had started sampling in 2016?

Describe the physical processes that drive the tropical climate.

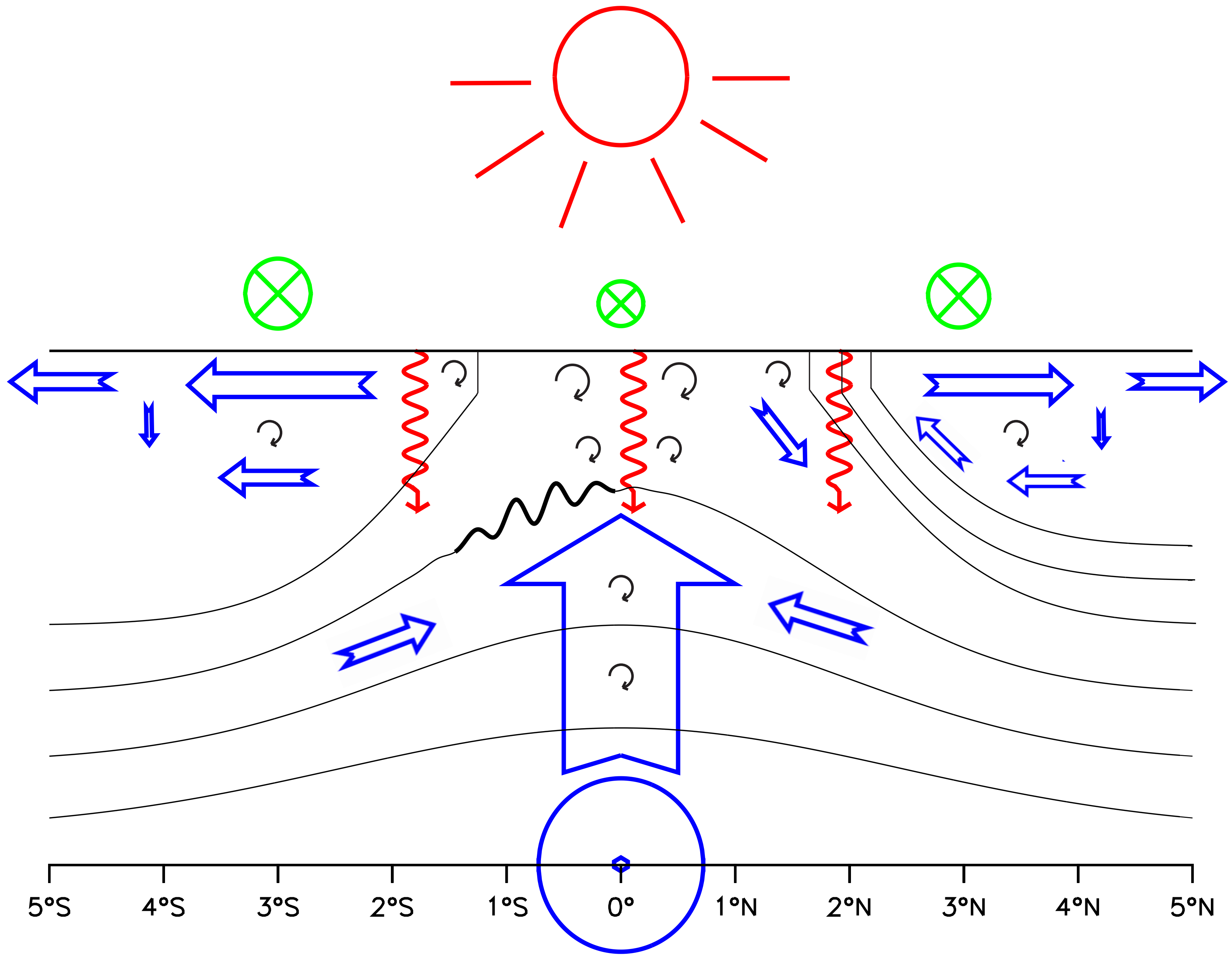
Integrate this understanding into models.

Maintain and build long time series:

High-quality data, detect weak trends
(Three examples ....)

The upwelling circulation

Upwelling __must be balanced__ by mixing and penetrating radiation



Risks

- In real life, funding might not respect the climate record.
- In our focus on T(z) and winds,

  we have neglected other important consequences:

  Nothing replaces the buoy surface met: Humidity and T_{air}, thus the LHF.

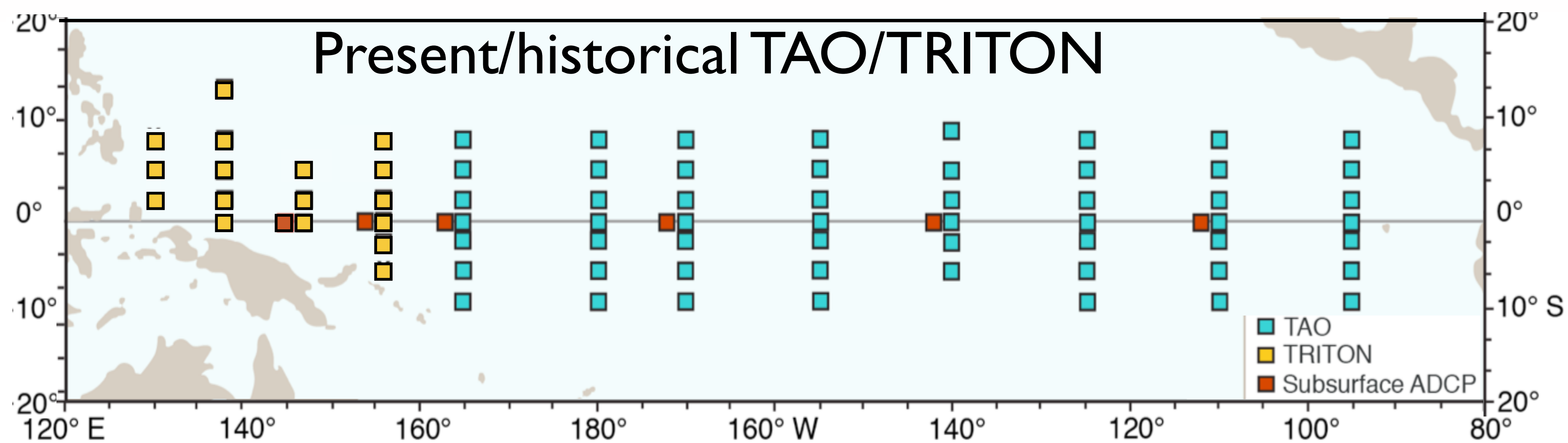
  Will those measurements turn out to be a key validator:

  - For coupling processes in models of 2030?
  - Or of techniques to infer these from future satellite retrievals?
  - How much flux measurement is needed? Where?
- Reducing mooring service cruises will damage the 25-year pCO_2 record.

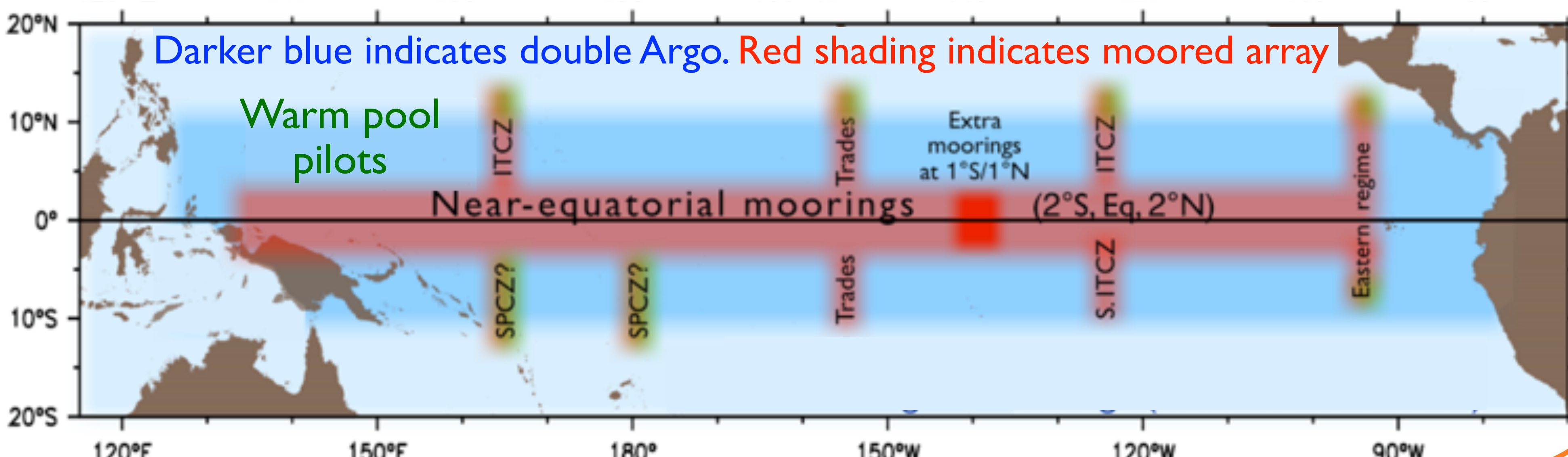
  Autonomous vehicles may mitigate this, but ...

Specific Recommendations

- Double Argo within 10°S-10°N
- Reconfigure the moored array:
  – more capable moorings, targeting: the equatorial circulation, the mixed layer and its interaction with the atmosphere, and key regimes



The eventual in situ "backbone"



Guiding principles

0. Do not repeat the mistake of changing observing systems without adequate overlap and evaluation!

1. Advance by observing the mechanisms connecting the equatorial thermocline and the free atmosphere. Challenge and guide model improvement.

2. Foster a diverse-platform observing system to adequately sample ENSO's rich multi-scale variability. Integrate tools that did not exist when TAO was designed:
   Satellites, Argo, new autonomous samplers, …

3. Beyond its monitoring capability, TPOS should serve as the backbone for essential ancillary and process studies (allowing others to propose and participate).