

The importance and challenges of regional scale analyses

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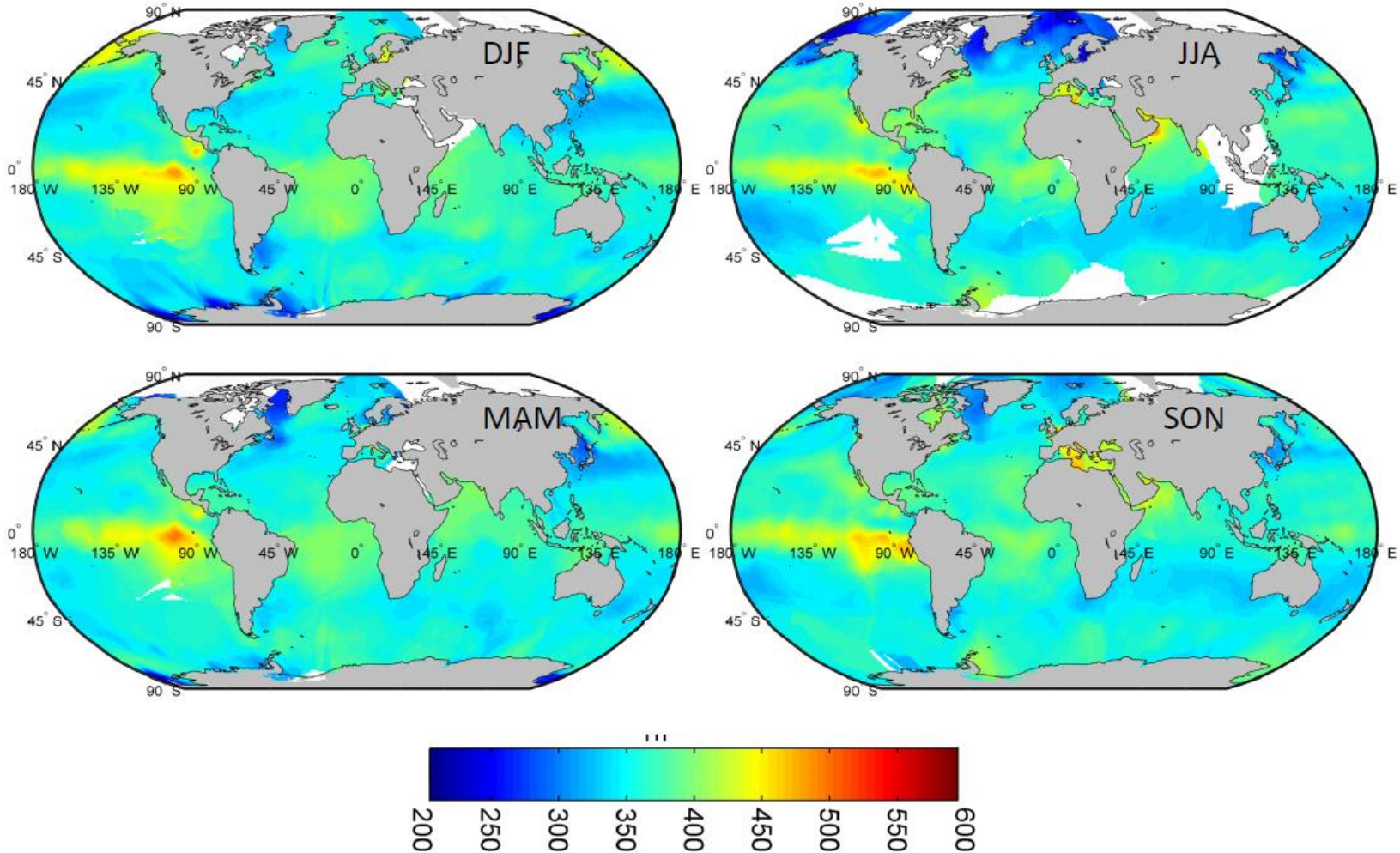
Overview

- Priority of estimating regional and seasonal fluxes
- Flux Equation and Flux Calculations
- Estimating Transfer Velocities
 - Intrinsic scales of measurements
 - Integration through parametric models
 - Risks of seasonal and regional biases
 - Validation against tracer studies
- Conclusions and Priorities

Why Regional and Seasonal?

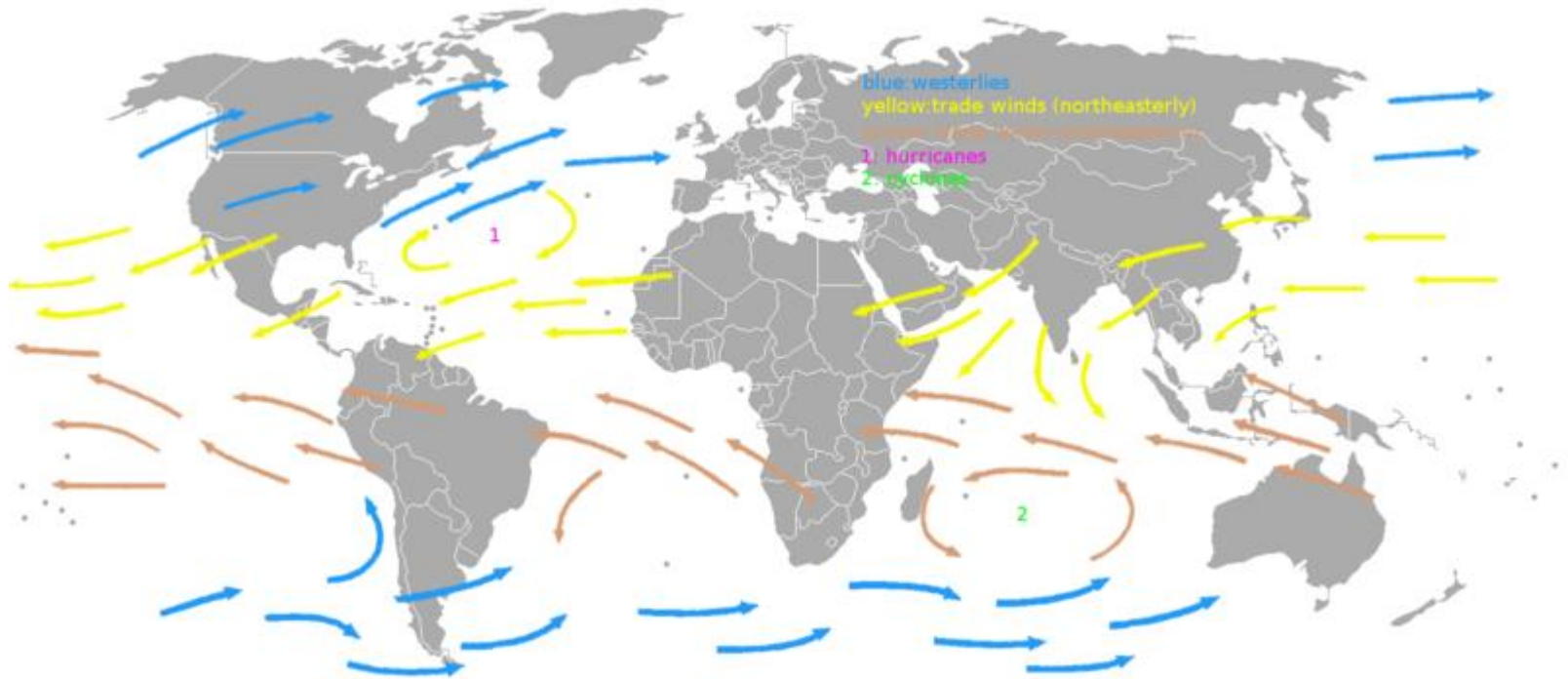
- Finest scale at which we can describe upper ocean concentrations
 - See map
- An appropriate scale to exchange data with other carbon cycle investigators
 - E.g. providing priors to inverse models
- ... but a case for high temporal resolution for operational models

Regional Analyses Ocean CO₂



mean $f_{\text{CO}_2, \text{d}}$ (μatm) from SOCAT V2 (std of monthly mean < 25)

Regional Analyses Wind Patterns



↑
Move North
in summer
↓

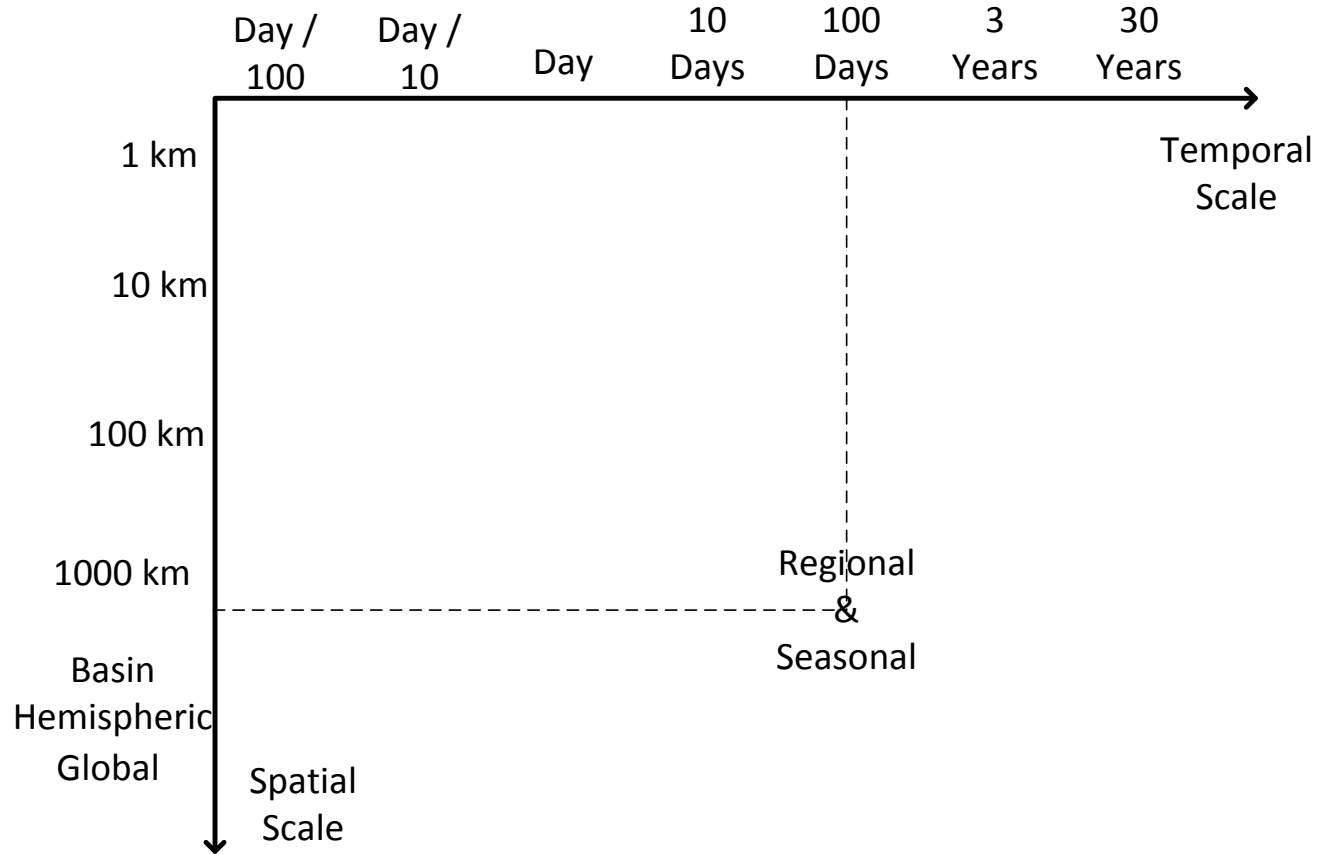
Flux Calculations

- Flux = $K_w (C_w - C_a)$
- Transfer velocity, $K_w \sim k_w$ (water-side control)
- Concentrations
 - Processed, but fairly direct measurement
- Transfer Velocity
 - Interpretation of a few measured K_w through a model of k_w

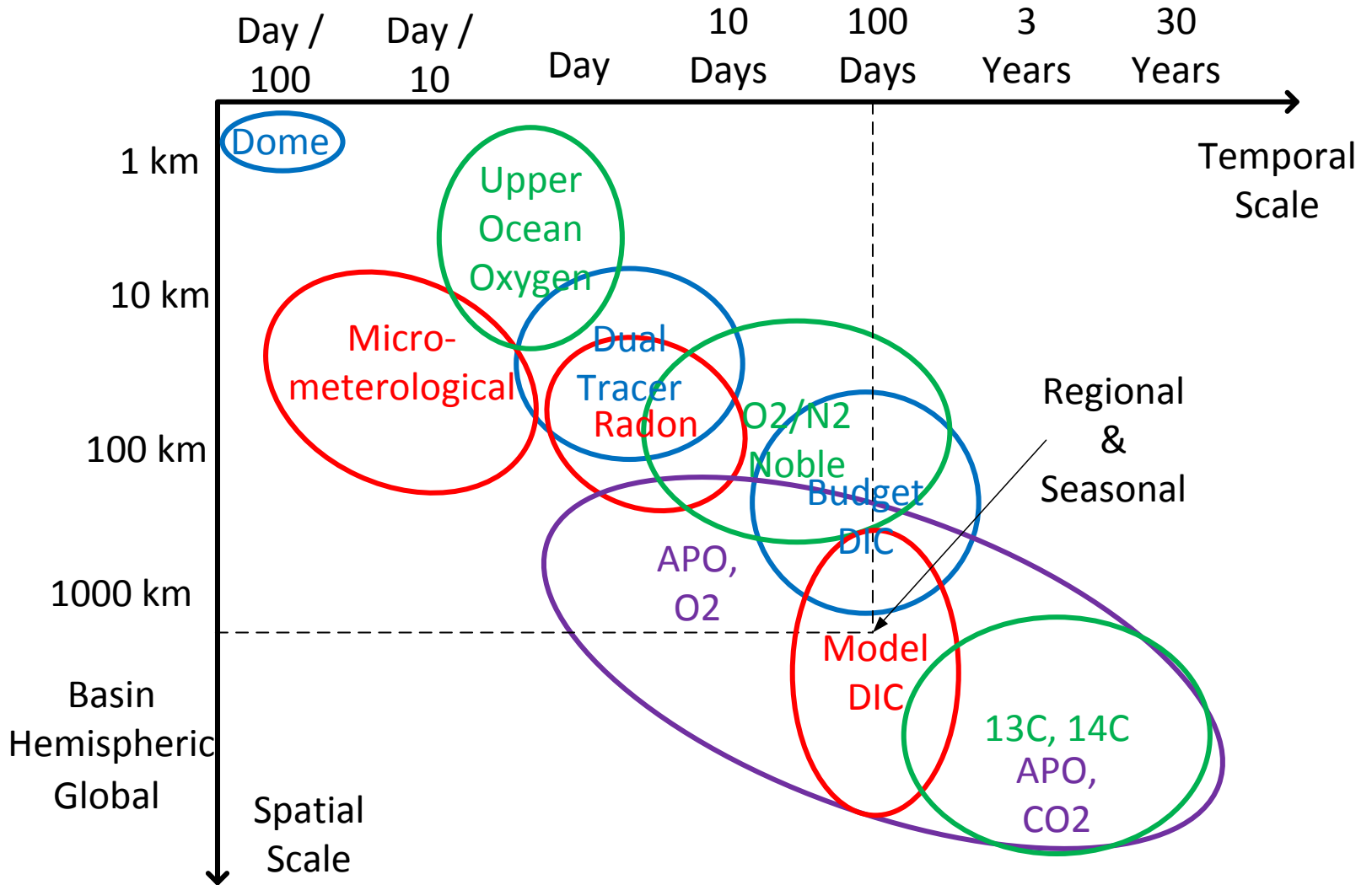
Estimating Transfer Velocities

- Methods of measurement and their intrinsic scale
- The construction of a model
- Possible errors in the model
- The expression of errors as systematic biases at regional and seasonal scales

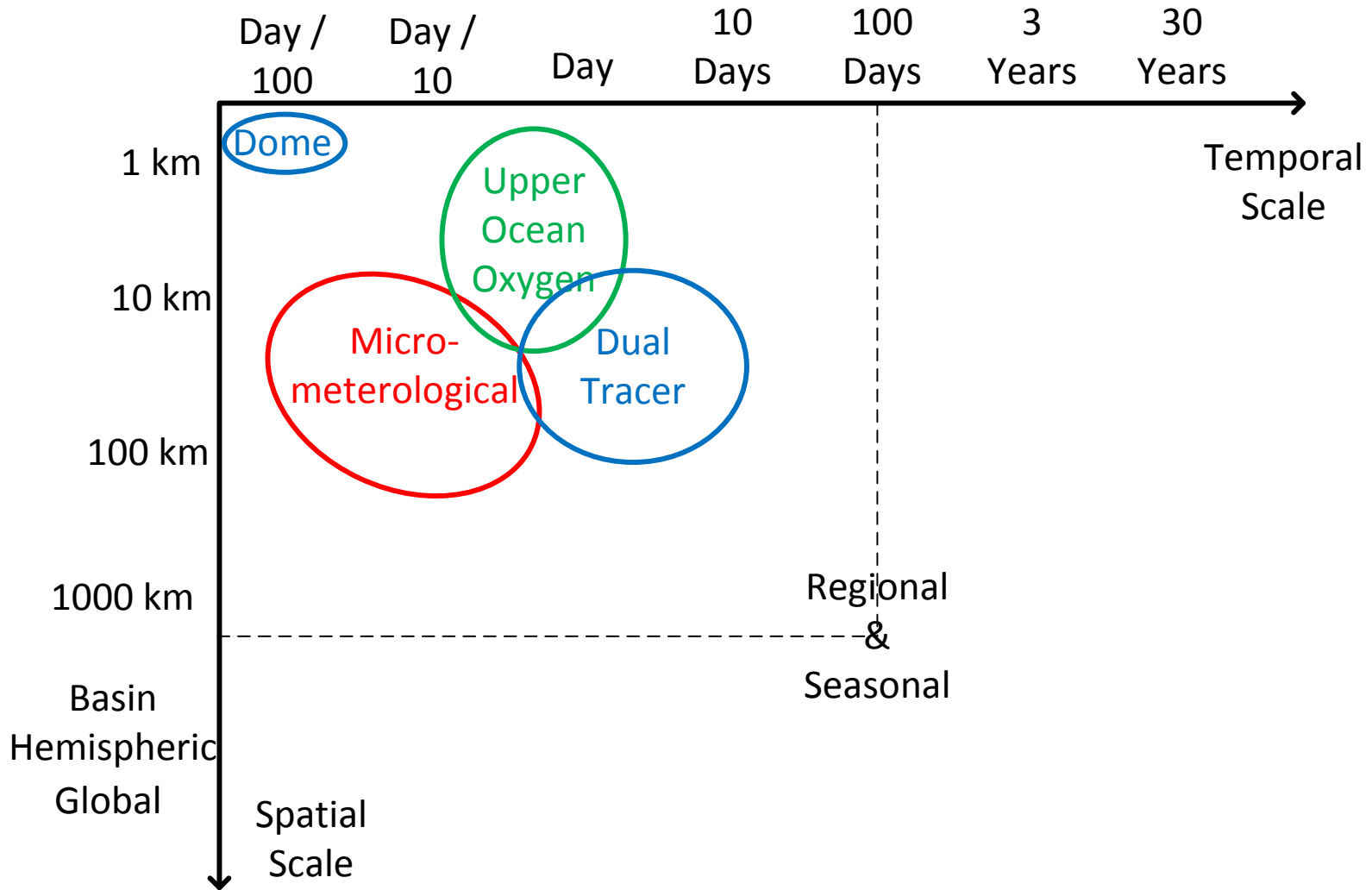
Scales of Interest



Scales of K_w



Scales of K_w



Constructing and Applying a Model

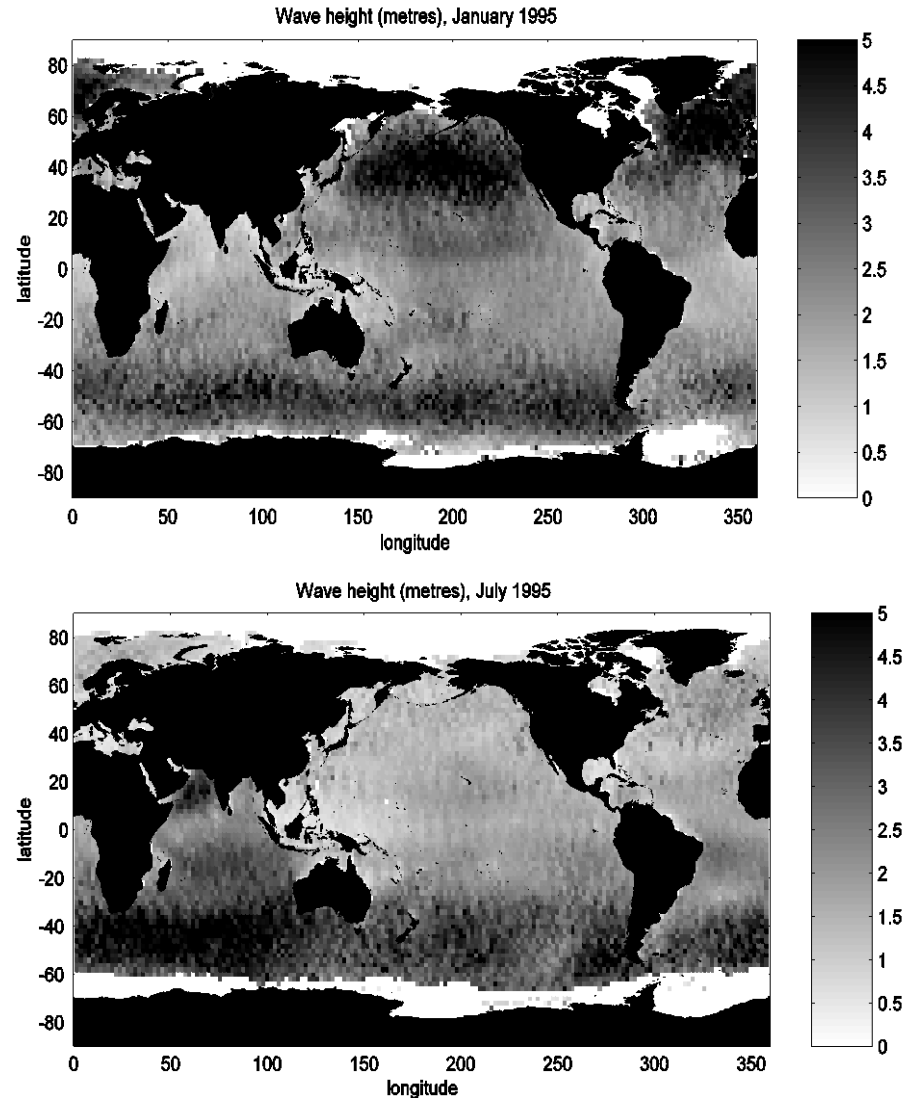
- Propose a practical model based on fragmentary information
 - E.g., specify $k_w = \text{Function}(U_{10N}, Sc)$
- Apply model globally to calculate k_w , K_w and Flux
 - Using best available in situ and satellite data (and models)
- Validate model performance wrt regional and seasonal fluxes
 - Does $f(Sc)$ adequately capture temperature dependence for a given gas?
 - Are there drivers other than U_{10N} that will vary systematically among regions and seasons
- Notes
 - Field determinations show substantial scatter but a large fraction can be attributed to experimental error (e.g. Asher, 2009). Possible that field data will never show unambiguously (presence or absence of) systematic variations (except between gases at high wind speeds?)
 - Laboratory and theory necessary for interpretation

Regional and Seasonal Sources of Bias

- A long list!
 - Temperature
 - Sc , Solubility
 - Whitecapping?
 - Fetch & Duration \longrightarrow Wave Development
 - Separation of tangential and wave stress
 - Wave breaking and whitecapping
 - Surface-active material
- Not obvious a simple model will capture regional and seasonal variation of K_w and k_w

Potential Sources of Bias Wave Development

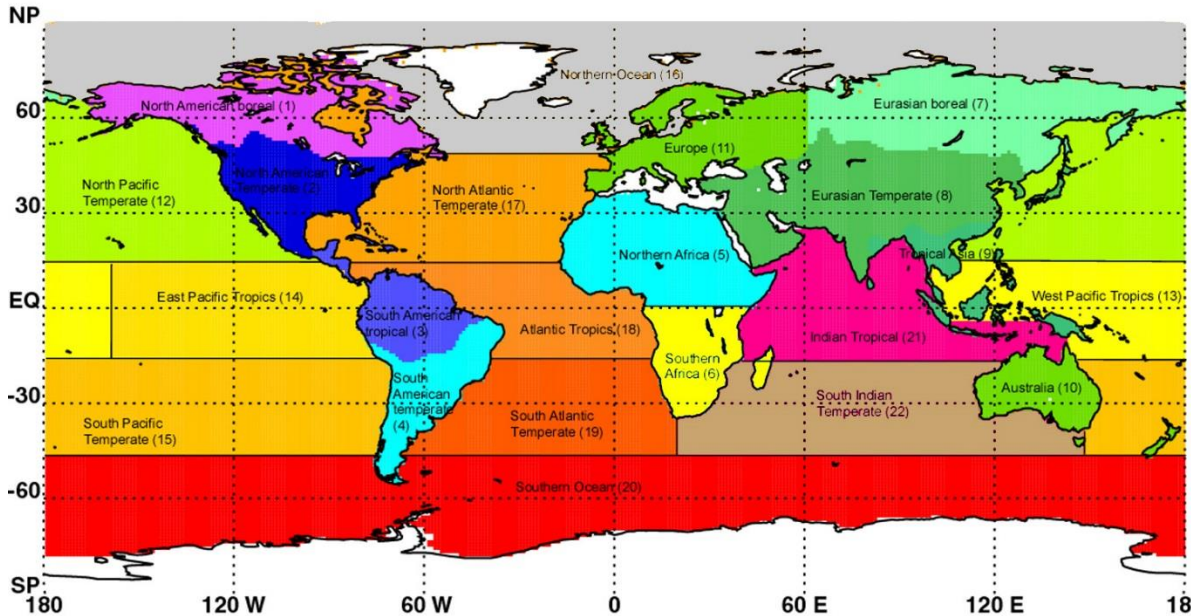
- Large wave heights mainly attributable to either winds in the mid-high latitude storm track or to Trade Winds, but also tropical storms and monsoons
- Regional and seasonal variations in relative significance of *wind seas* and *swell* from high-latitude storms.
- Typical *Fetch* and *Duration* also vary with region, e.g.
 - Short duration and fetch typical of Arctic seas (Polar Lows and geography)
 - High fetch but limited Duration typical of Southern Ocean
 - High Fetch and Duration typical of Trade Winds



Validation

- We use theory, laboratory experiments and relatively local measurements of K_w to construct our models.
- We need independent information to validate those models.
- A globally-averaged transfer velocity or flux is often used, but ...
 - Is a single-point calibration or validation
 - Maybe sensitive to poorly sampled regions
 - Maybe sensitive to systematic biases that are relatively insignificant more locally (e.g. “cool skin” and “bubble injection” for net global CO_2)
 - Insufficient to validate regional and seasonal values
- Preferable to find regional (and ideally seasonal) information for validation.

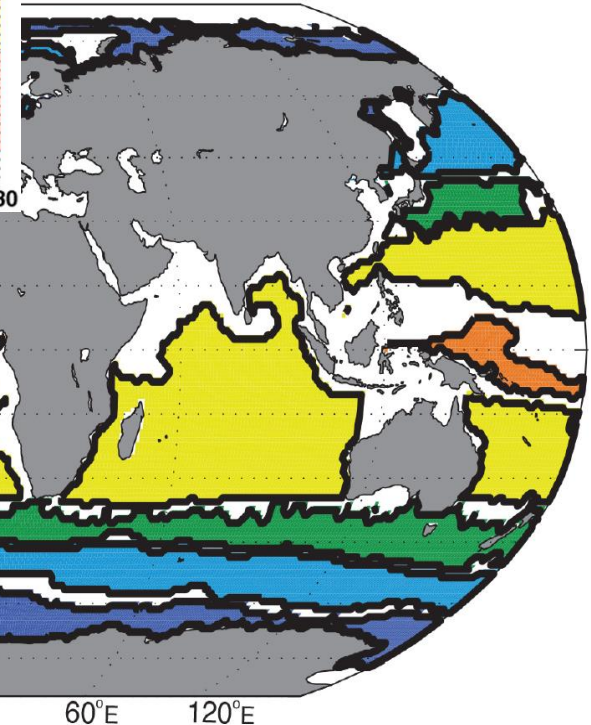
Validation by Region



TransCom

- Arbitrary
- Hard Boundaries
- No Time Variation

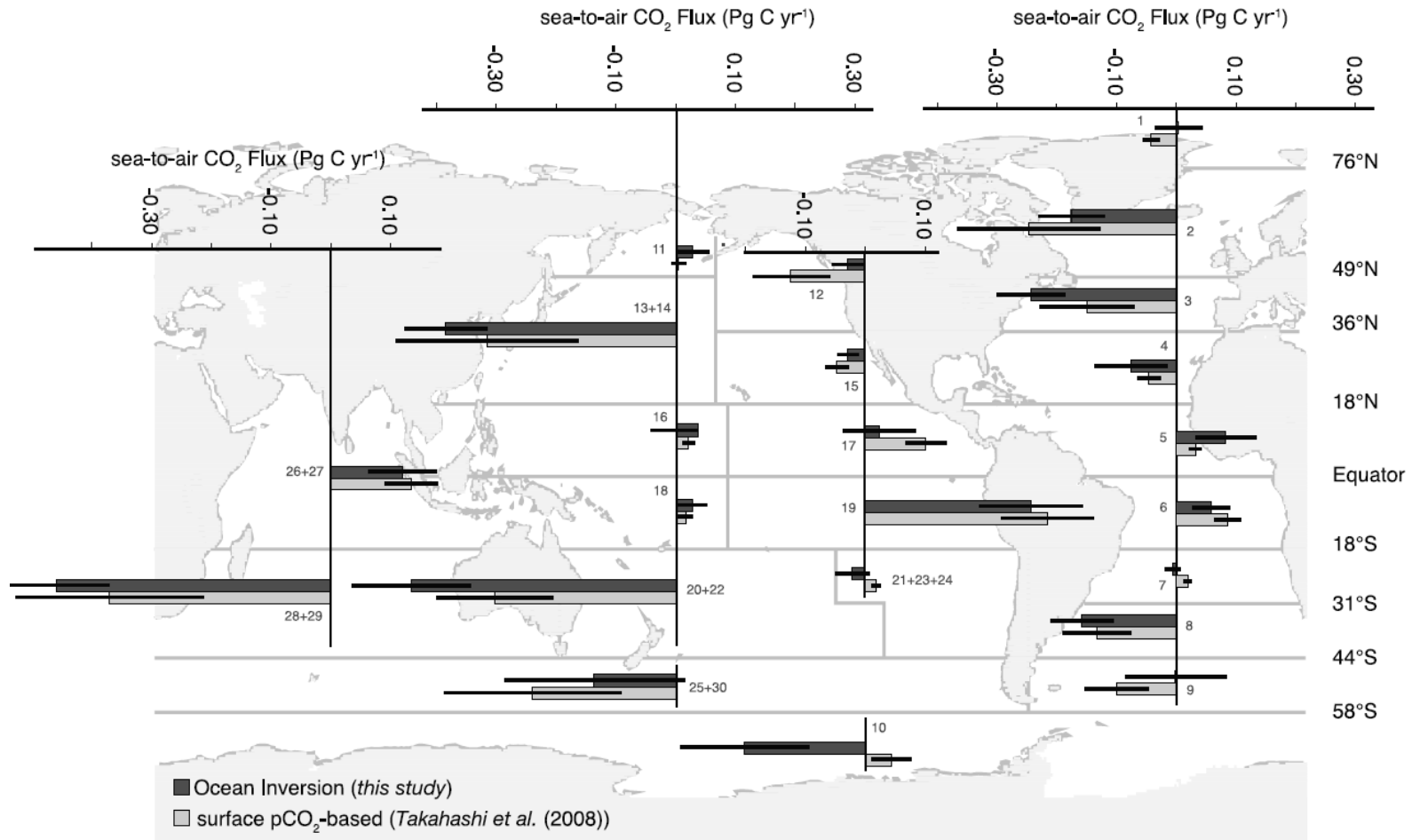
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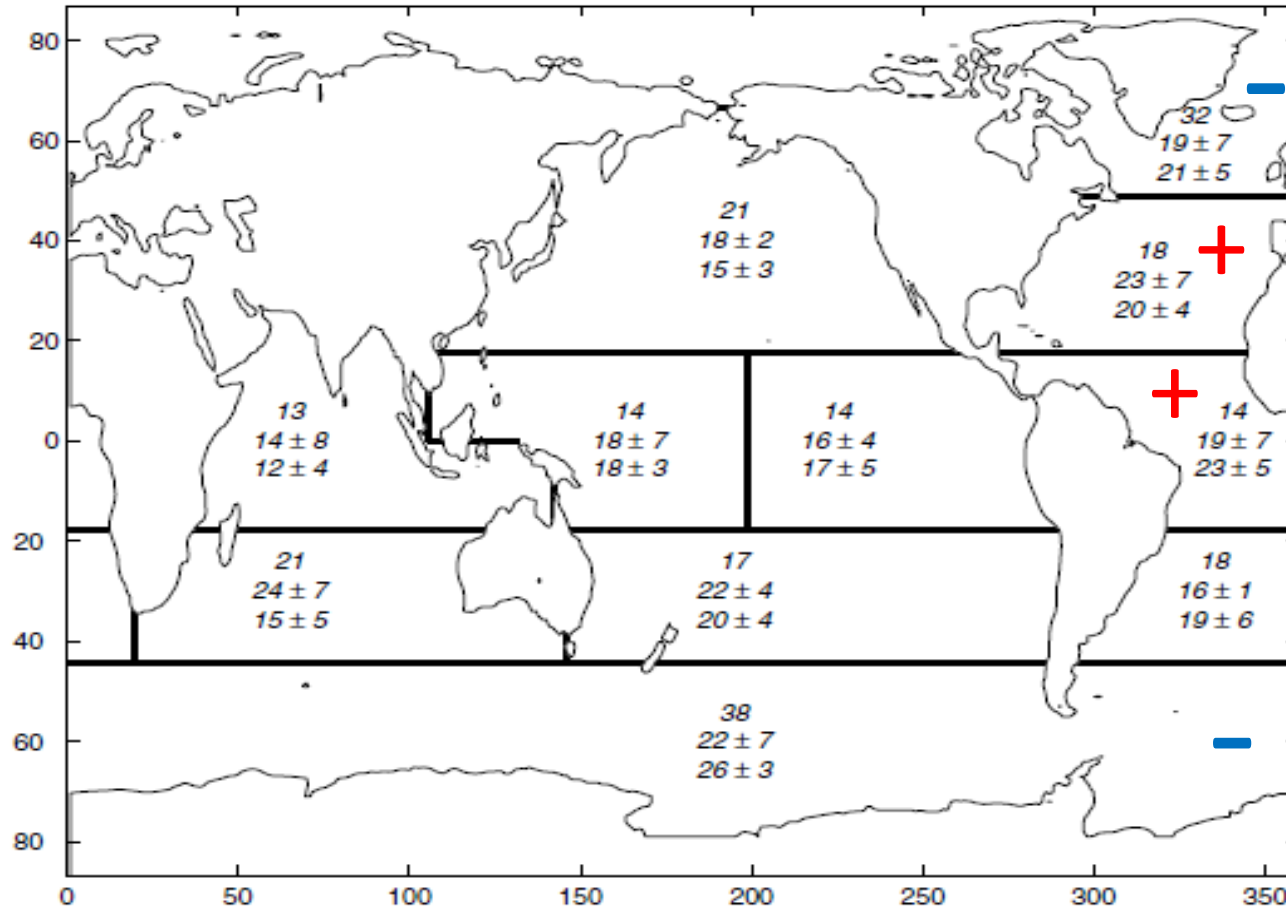
Fay & McKinley 2014

- Multi-criterion biomes
- Flexible Boundaries
- Inter-annual but not seasonal

Validation CO₂ Fluxes



Validation Transfer Velocities



While the pattern of CO₂ fluxes is encouraging, The implied regional variation in transfer velocity is puzzling. Especially in the Atlantic.

Conclusions & Foresight

- The success of models of k_w at regional and seasonal scales is essential but unproven
- Validation of fluxes and transfer velocities at regional and seasonal scales is essential
 - Revisiting Gruber et al., 2009 & Krakauer et al., 2006
 - New air-sea flux calculations (& deep ocean measurements)
 - Choice of region
 - New tracers/validations
 - “Deep ocean” validation is intrinsically “multi-year”; need for seasonal validation
- Focussed laboratory experiments on effect of wave development