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THE OBVIOUS QUESTION

What am I doing here
1) Observing Air-Sea Interaction  ➔  Model Forcing and Coupling
2) Instrument Development  ➔  Model Development
3) Ocean Observations  ➔  Model Parameterizations

WHERE TO NOW?

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1) Observing Air-Sea Interaction

DRAG COEFFICIENT \( C_D = \left[ \frac{\kappa}{\ln(10m/Z_0)} \right]^2 \)

DALTON NUMBER \( C_E = \left[ \frac{\kappa}{\ln(10m/Z_E)} \right] \sqrt{C_D} \)

STANTON NUMBER \( C_H = \left[ \frac{\kappa}{\ln(10m/Z_H)} \right] \sqrt{C_D} \)

\( Z_0 = \) function of wind speed

\( Z_E = 9.5 \times 10^{-9} \) m

\( Z_H = 4.9 \times 10^{-9} \) m, unstable ;

\( = 2.2 \times 10^{-9} \) m, stable
1) Ocean Model Forcing and Coupling

Haney (1971): infinite heat capacity atmosphere

--- air-sea heat flux into ocean = \( k(x,y) \left( T^*(x,y) - \text{SST}_{\text{model}} \right) \)

CORE (Coupled Ocean-Atmosphere Research Experiments):

PROTOCOL: \[ \text{FRANK BRYAN; GOKHAN DANABASOGLU} \]

FORCING:

BULK --- Wind Stress; Sensible heat; Latent heat and Evaporation

ATMOSPHERIC STATE ----- “corrected” NCEP/NCAR \[ \text{STEVE YEAGER} \]

----- “corrected” JMA-55 \[ \text{HIROYUKI TSUJINO; WHO KIM} \]
1) Observing Air-Sea Interaction

$C_D$, depends on wave spectrum

DIRECTIONS

HOURLY VARIABILITY

SATELLITE SCATTEROMETRY

NR stress

Wind (m/s)

0 5.0 10.0 15.0

0 6 12 18 24 30 hours

$10^3 C_D$

0 1.0 2.0

$u^*$ (high frequency)

0 .2 .4 .6 .8 m/s

$u^*$ (eddy-correlation)

0 .2 .4 .6 .8 m/s

0 .2 .4 .6 .8 m/s

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2) Instrument Development

A) AIR-SEA FLUX SYSTEM [STEVE POND, ED MEYER (EE)]

- 26 circuit boards (50 mW)
- Analogue sensor and band-pass filters
- Digital processing (e.g. 12-bit multiplier of NOR gates, J-K Flip Flops)
- Cassette Tape (Fixed to Floating Point Converter)

MADE OBSOLETE BY MIRO-PROCESSORS & DVDs BEFORE FIRST DEPLOYMENT
B) CASID (Climate Air-Sea Interaction Drifters)
Thermistor Chains

[JIM McWILLIAMS, PETER NIILER, PRL]

NCAR:
Atmosphere Technology Division (ATD→EOL)
NOT Ocean Technology
1) FLUX COUPLER [**CESM SCIENTISTS & SEs**]
--- The 4 dimes and a quarter roadblock
--- Component Instability (e.g. CAM Pixie Dust)

PROPOSED

SOLUTION

“MARVELOUS SE HEROS”

SEWG (CISL, DOE)
1) MODEL DEVELOPMENT & SE

Diurnal Cycling

SST [**JULIE CARON**]

SSS [**EFFIE FINE**]

AMSRE SST

- 1 °C
- 0.8
- 0.6
- 0.4
- 0.2
- 0.08 PSU
- 0.05 PSU

SSS RAINY DAYS

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3) OCEAN OBSERVATIONS

Storm Transfer and Response (STREX)
Ocean Storms

Findings:

• About 1°C cooling to 50 m in 6 hours $\Rightarrow$ 1500 W/m²
• Spatial scale of response only 50 – 200 km
• Net surface heating $\Rightarrow$ wind driven mixing from below
• Diffusivity (Vertical Flux / Gradient), $K_v = 400 \rightarrow 1000$ times molecular ($\mu$)
3) **CASID**

**COOLING EVENTS**

\[ \sigma = \frac{d}{h} \]

\[ K_t = 1000 \, \mu \]

\[ K_t = 400 \, \mu \]

Jim Price reports

“P-W-P Mixed-Layer Model unable to cool”
KPP: [JIM McWILLIAMS, SCOTT DONNEY]

--- John Wyngaard (MMM) suggests K-Profile approach from Atmosphere (Troen & Marht)
--- 2-years to develop KPP; does mix and cool
--- CAM becomes similar (Holtslag & Boville)
--- Not for long (Bretherton & Park)

INERTIAL RESONANCE [GREG CRAWFORD];
PWP then cools (enough?)
Analogy with molecular diffusion; \[ \text{Flux} = K \ (-\text{Gradient}) \] does not apply to turbulent boundary layers \[ \text{Flux} \neq 0 \ ; \ \text{Gradient} = 0 \]

\[ \text{Flux} = K \ (-\text{Gradient} + \gamma) \]

WHAT DO LARGE EDDY SIMULATIONS (LES) SAY?

[ PETER SULLIVAN & NED PATTON (MMM);
DOROTHY KOCH (DOE); ALICE DuVIVIER ]
LARGE EDDY SIMULATIONS (BUOYANCY)

EDDY DIFFUSIVITY, $K_S$

- $\text{Flux} = K \left( -\text{Gradient} + \gamma \right)$

- $w_S(\epsilon h) (\sigma h) = \frac{\text{Flux}(0)}{\text{Gradient}(\epsilon h)}$

- $Z_0 ; \text{Flux} = 0 ; \text{Gradient}(Z_0) = \gamma_S$

- "$K_S(z)" = w_S(\epsilon h) h G_S(\sigma) = \frac{\text{Flux}(z)}{\text{Gradient}(Z_0)}$

- *M-O scaled up, HOW?*
LES SHEAR AT DEPTH

Surface Layer M-O Similarity

\[ w_m(\epsilon h) (\epsilon h) = \frac{\text{Wind Stress}}{\text{Shear}(\epsilon h)} \]

Below Surface Layer

Wind Stress

LES shear

\[ U_{dn}, U_{up} \]

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LES MOMENTUM FLUX & SHEAR

\[ \text{Flux} = K (-\text{Gradient} + \gamma) \]

\( (K\gamma)_m = \text{cross-shear flux} \)

\( \gamma_m = \text{no-flux shear} \)

\[ \text{“}K_m(z)\text{”} = \]

\[ w_m(eh) h G_m(\sigma) = \]

\[ \text{cross-shear flux} \]

\[ \text{no-flux shear} \]

\[ \Omega \]

\[ \text{LES shear} \]

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Both calm AND wavy cases

\[
G_m(\sigma) = \frac{\epsilon \text{ Shear}(\epsilon h)}{\text{Stress}(0)} \quad \text{cross-shear flux}
\]

\[
G_s(\sigma) = \frac{\epsilon \text{ Gradient}(\epsilon h) \text{ Flux}(z)}{\text{Flux}(0) \text{ Gradient}(Z_0)^*}
\]

\[
\text{cross-shear flux} \sim \text{cross-shear wind stress}
\]
SHAPE FUNCTIONS

MOMENTUM or BUOYANCY & CALM or WAVY

$G(\sigma)$

- $G_m(\text{calm})$
- $G_s(\text{calm})$
- $G_m(\text{wavy})$
- $G_s(\text{wavy})$

Shape function of
--KPP
--Holtslag - Boville
SUMMARY

• Model development hierarchy: LES to CESM
• Ocean boundary layer: Waves and Non-local Stress
• $C_D$ (wind & wave spectrum)
• Coupled Wave Model: How sophisticated?
• Exchange Reservoir
That’s All Folks !!
SINGLE LATERAL EDDY VISCOSITY set by **NUMERICAL STABILITY**

--- Equatorial Undercurrent \(\sim 10\) cm/s (observed \(> 100\) cm/s)

**ANISOTROPIC VISCOSITY**  
*Jim McWilliams*

--- Downstream (numerics) \(>\) cross-stream (physical)

--- Scale-aware function of grid size

--- Equatorial Undercurrent \(> 100\) cm/s