The Total Energy – Mass Flux PBL Scheme: Overview and Performance in Shallow-Cloud Cases

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Target applications and resolution

- Stable boundary layers
- Shallow / fair-weather cumulus cases
- Horizontal grid a few km or more
  - Will work with finer grid but cloud statistics not good
- Vertical grid:
  - First level 10-20% of minimum PBL depth
  - Stretching by no more than 3x per level

The stable side (Mauritsen et al. 2007 JAS)

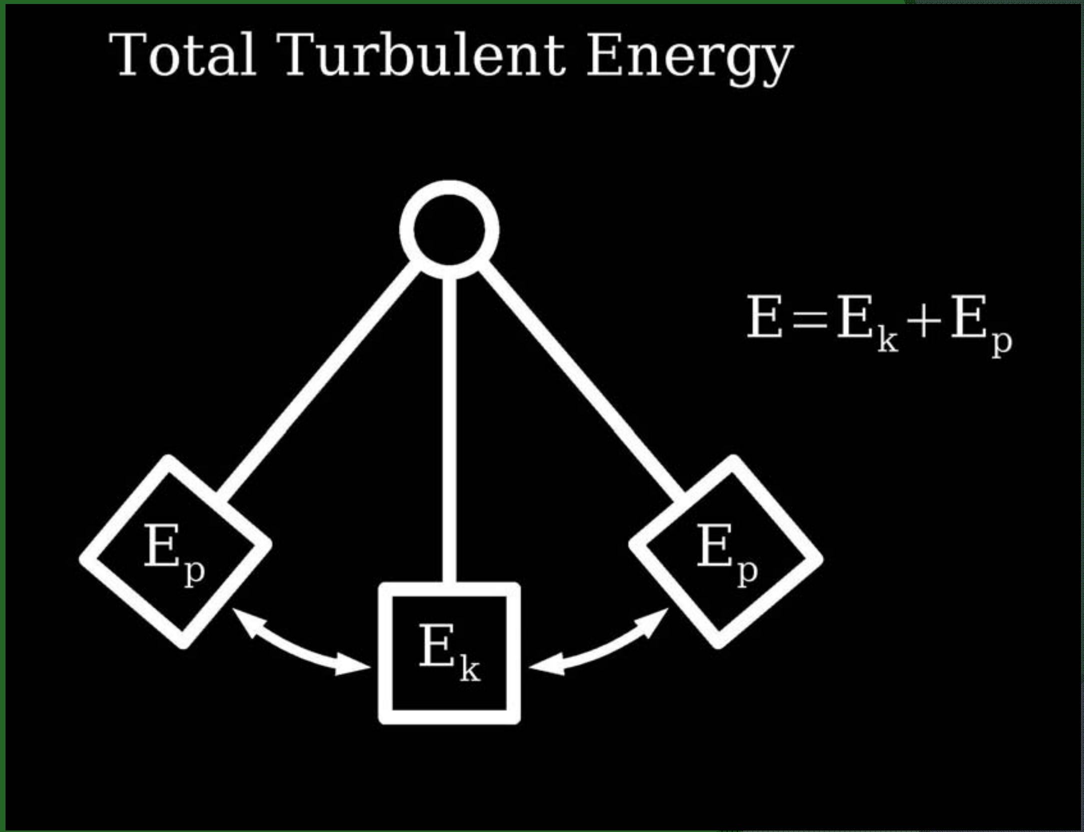
- Use of total turbulent energy in stable stratification (potential + kinetic energy)
  - therefore no implicit critical Ri
- Use of local gradient Ri stability functions
- Length scale incorporates z, f and N
- Avoids self-correlation in selection of empirical coefficients
- Tested in almost 100 LES cases

Why do we use TE instead of TKE?

For any mechanical system, both kinetic and potential energy are needed for a full description (for example, a pendulum)

Recall that TE – length scale formulation is used in all stable layers of the column, not just in surface-based BL

Practically, TE allows for appropriate mixing in stable layers rather than cutting it off quickly as TKE would



Stability functions

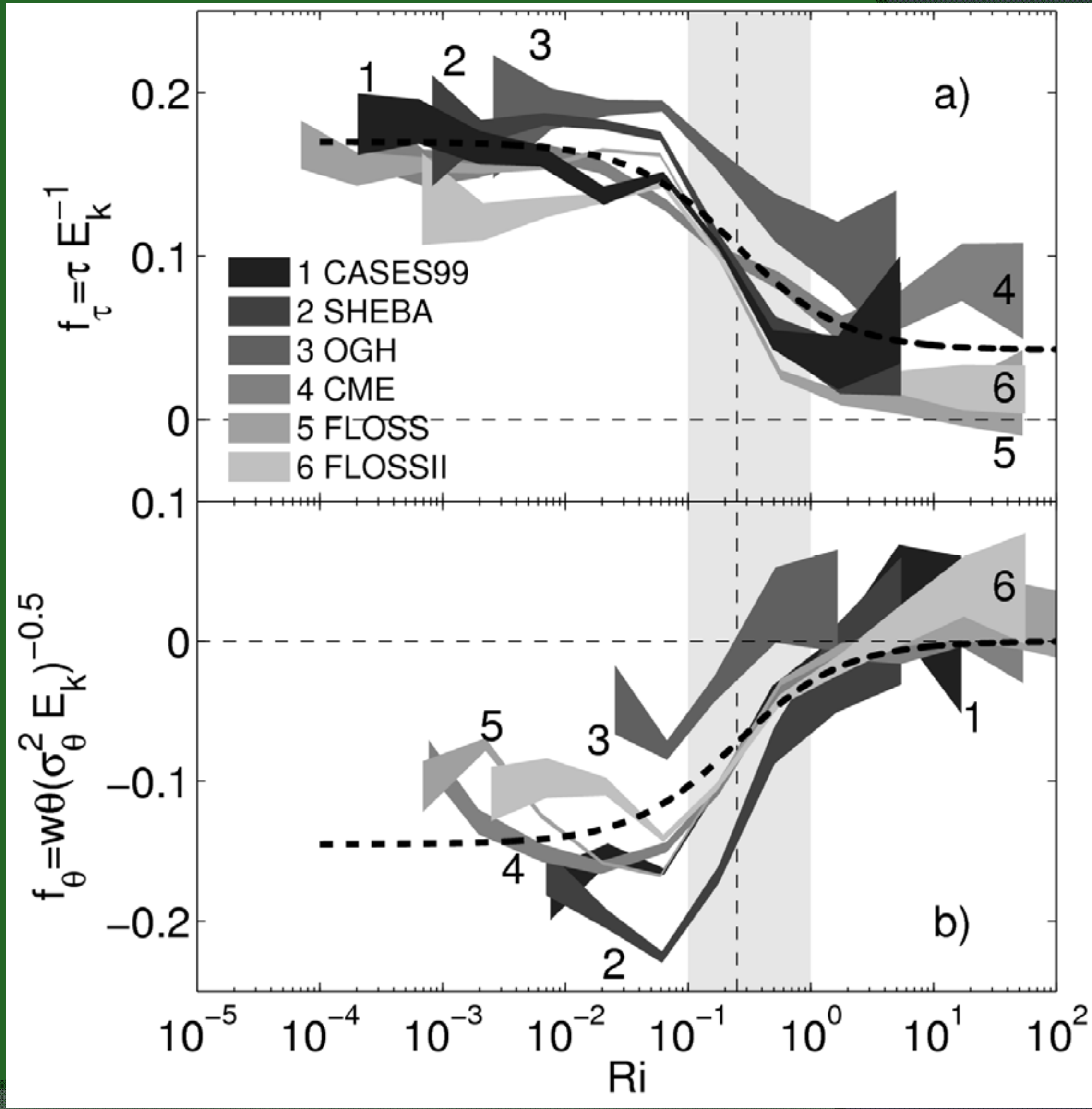
Dashed lines show empirical fits used in the scheme

(Normalized) momentum transport continues at high Ri

(Moderately) sharp tails

Momentum

Heat



The convective side (Angevine 2004 JAM)

- Eddy diffusion – Mass flux (EDMF) scheme
- Patterned after work by Siebesma, Teixeira, and others
- Diffusion coeffs. based on total energy (TE)
- Mass flux transports all quantities, including TE, U, V
- Length scale based on distance from surface and inversion

Differences between TEMF and other EDMF schemes

Entrainment & detrainment rates

TE rather than TKE or profile as basis for diffusion coefficients

Length scale (minor differences?)

Cloud base mass flux is continuous and proportional to w*

Mass flux and updraft velocity are prognostic, area fraction not (directly) specified

Updraft properties initialized at z_0, no excess

No explicit top entrainment

Surface layer uses same stability functions as BL, not M-O

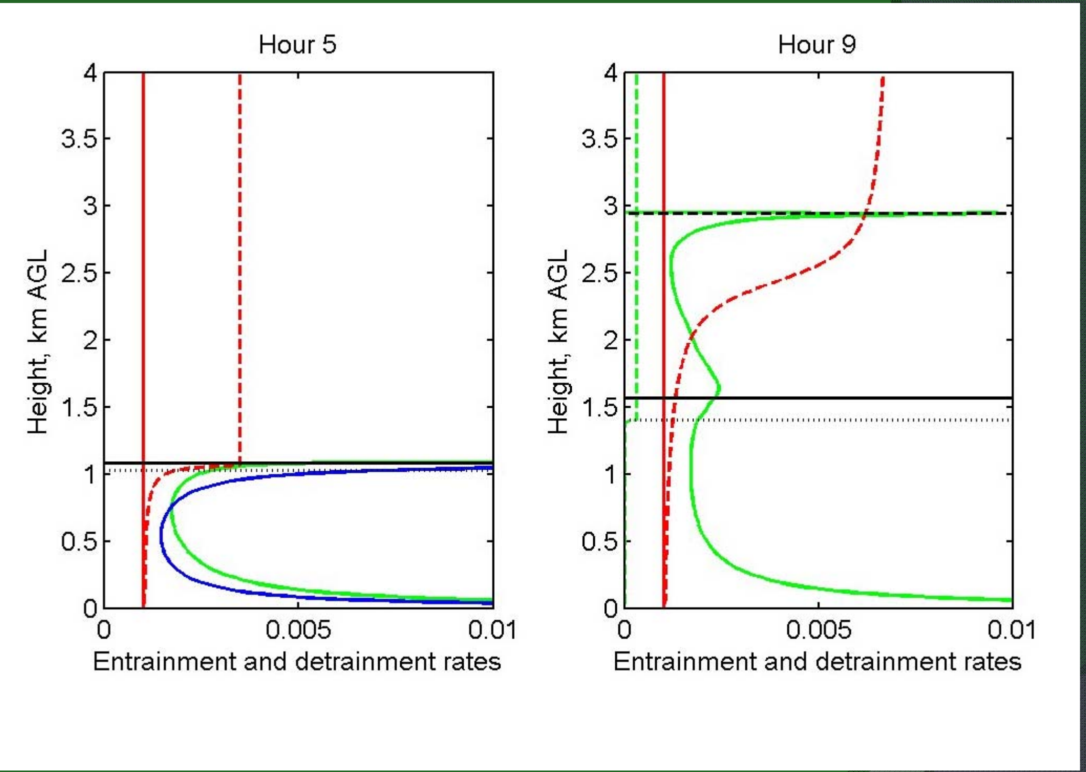
Entrainment and detrainment rates

The only sensitive part of the scheme

Current version uses epsilon ~$1/z_i$

Example:

GOMACCS 11 Sept.



Red = TEMF

Green = ECMWF

Blue = Siebesma et al. (2007)

Solid = epsilon (lateral entrainment), dashed = delta (detrainment)

Total Energy vs. TKE

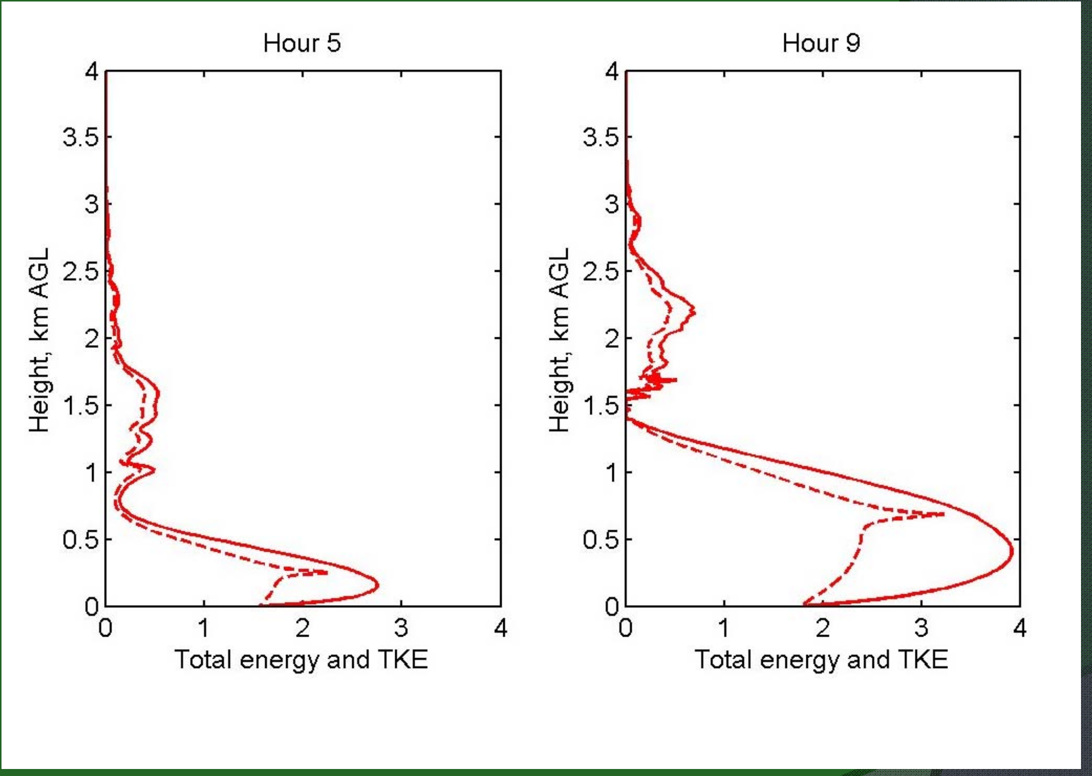
GOMACCS 11 Sept.

Solid = TE, dashed = TKE

TKE is slightly smaller throughout

Most significant in upper BL

Caution: A TKE-based scheme would probably produce a different TKE profile and use different stability functions



Length scale

Master length scale:

$$\frac{1}{l} = \frac{1}{kz} + \frac{f}{C_f\sqrt{\tau}} + \frac{N}{C_N\sqrt{\tau}}$$

N not allowed to be < 0

Convective length scale gives more mixing in upper part of convective BL, used when larger than master scale:

$$\frac{1}{l_{conv}} = \frac{1}{kz} + \frac{3}{k(h_d - z)}$$

Cloud base closure

Mass flux is continuous at cloud base

Updraft properties are modified by entrainment during ascent through subcloud layer

Velocity and therefore area fraction change during ascent

- typical values at cloud base 4-6%

Updraft initialization

$M(z_0) = 0.03\, w_*$

$w_{upd} = 0.5\, w_*$

So updraft area fraction = 6% at z_0

- epsilon = delta until near top, so area fraction stays roughly constant

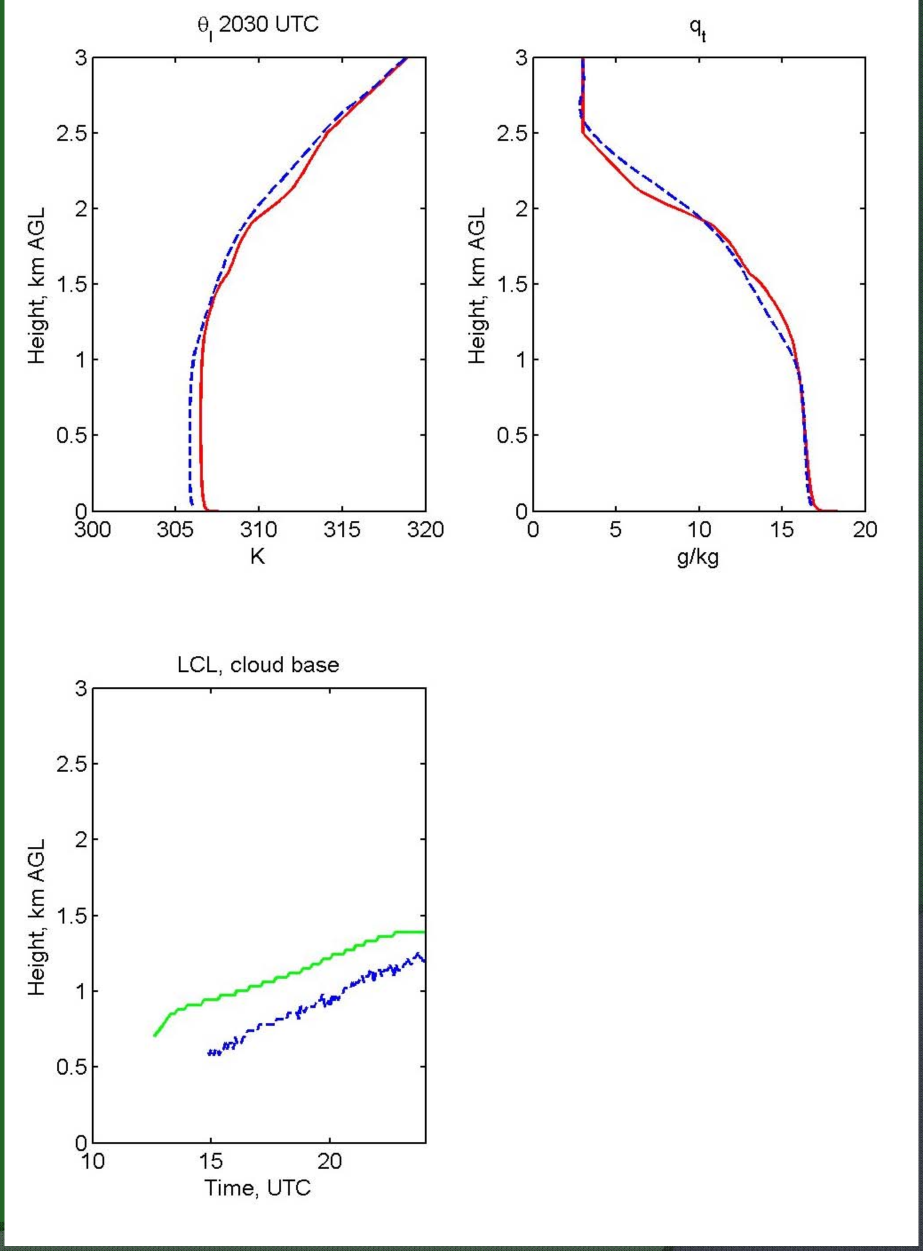
All other properties take the environment values at z_0

- difference between surface and bulk values is proportional to surface flux

ARM case

Red, solid = TEMF,

Blue, dashed = KNMI LES (thanks to Geert Lenderink)



The GOMACCS cases

Gulf of Mexico Atmospheric Composition and Climate Study

September 2006

LES simulations with RAMS/LES

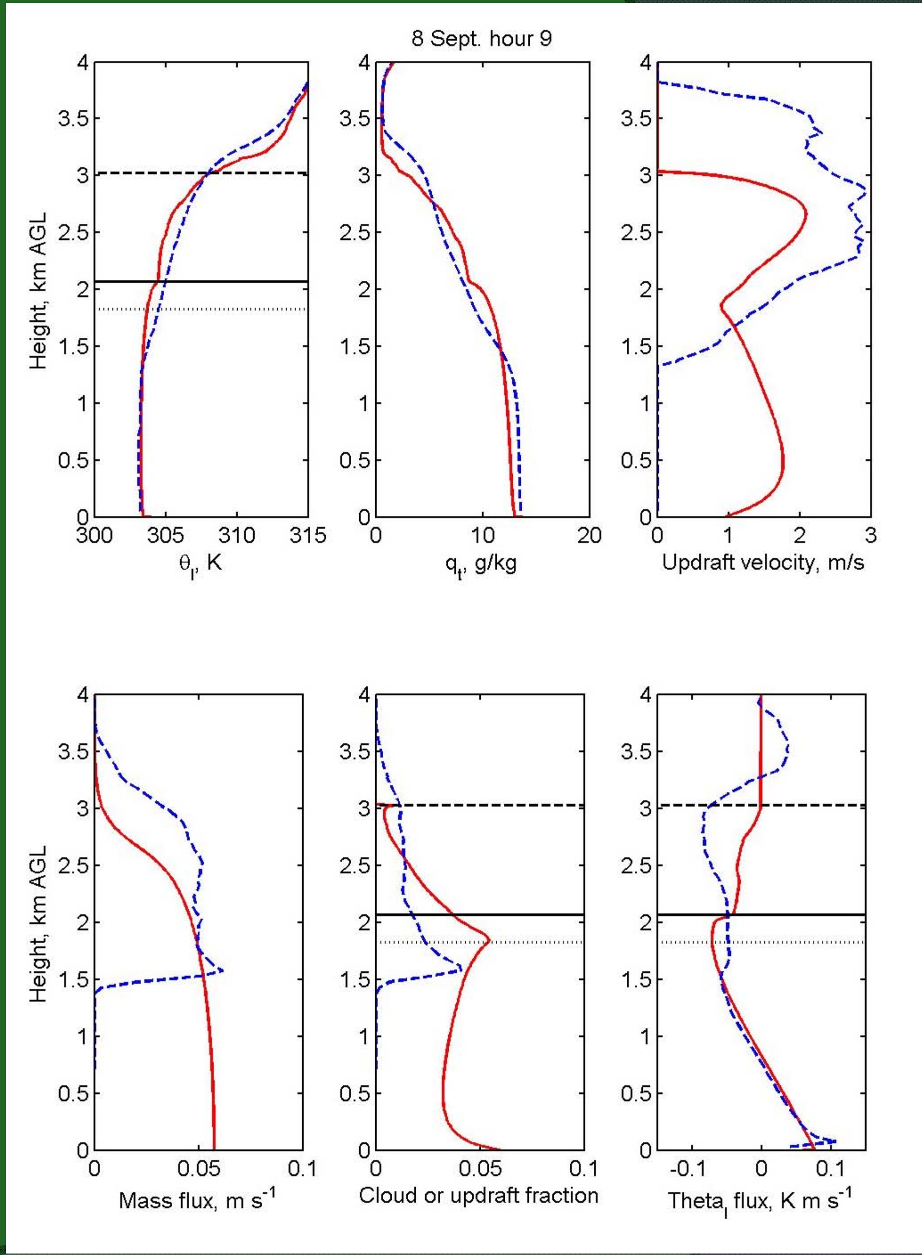
Shallow cumulus over land

TEMF 1D / SCM in Matlab

Boundary conditions from LES

TEMF vs. LES
8 September

- Profiles at 1500 LST as labeled
- Red = TEMF, blue = LES
- Good correspondence in theta and q
- Reasonable correspondence in cloud parameters (note these are snapshots)



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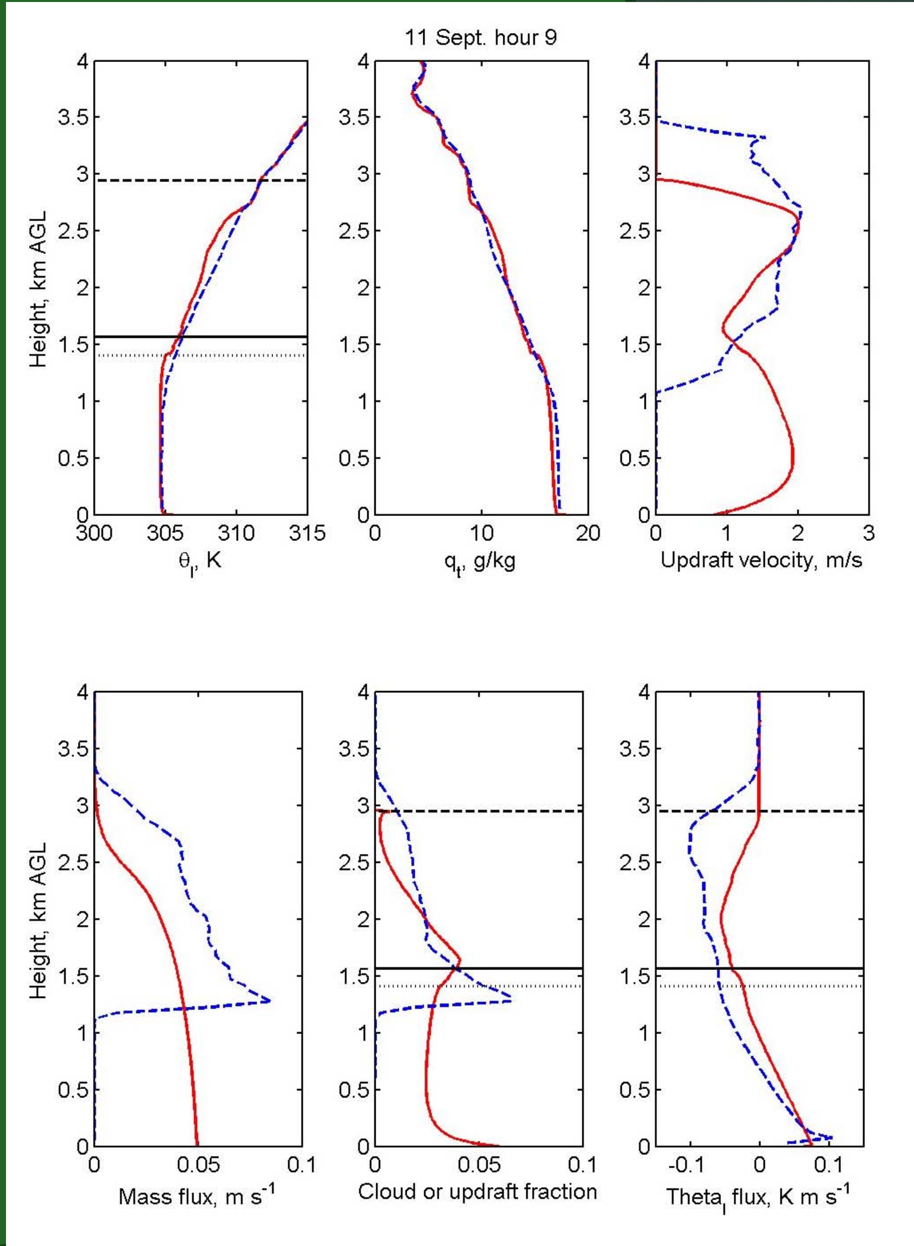


Southern California Bight Evaluation

- CalNex air quality and climate study
  - May-June 2010
- WRF-TEMF run for two months in real-time forecast mode
  - One major retro run since, another underway
- 16 May case study chosen because aircraft and ship were present and interacting in cloudy area
- P3 provides profiles and tracks in and above cloud
- Atlantis provides continuous cloud base, top, and fraction

Model configurations

WRF REF:

36/12/4 km horizontal grid

ERA-Interim initialization (was GFS for forecast)

60 vertical levels, 18 below 1 km, lowest level ~15 m

Eta microphysics

RRTM-G radiation (LW & SW)

Grell-Devenyi cumulus, outer domain only

MYJ boundary layer & surface layer

Navy GODAE high-resolution SST (6-hourly)

WRF TEMF:

Same as REF except for TEMF boundary layer and surface layer on domains 2 and 3

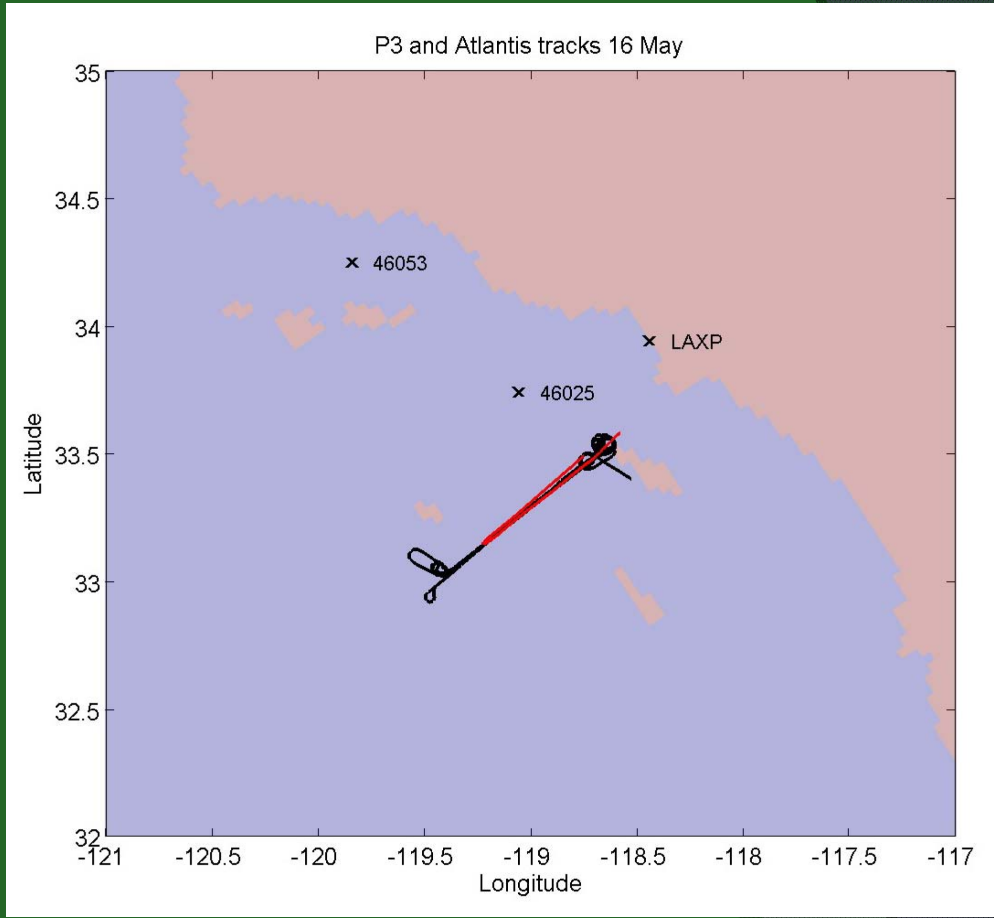
COAMPS:

Navy operational mesoscale model run at Pt. Mugu by Lee Eddington

NOGAPS initialization, warm start mode, no data assimilation

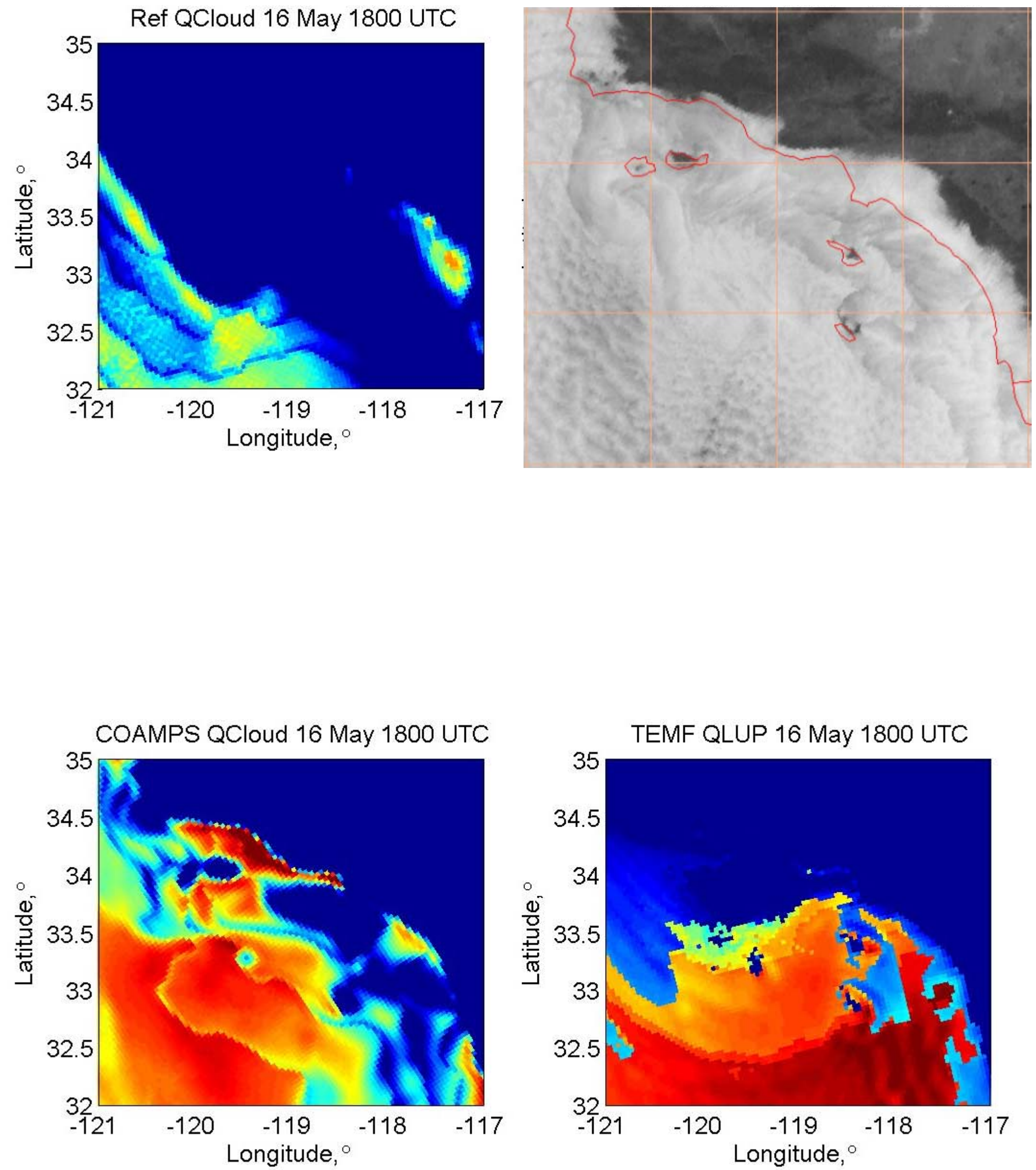
P3 and Atlantis cloud study track

P3: 1818 – 2124 UTC
Atlantis: 1800 – 0000 UTC



Cloud liquid 18Z (ERA)

Color scale is 0 – 5e-4 (max values ~0.5 g/kg)



Profiles on P3 track (ERA)

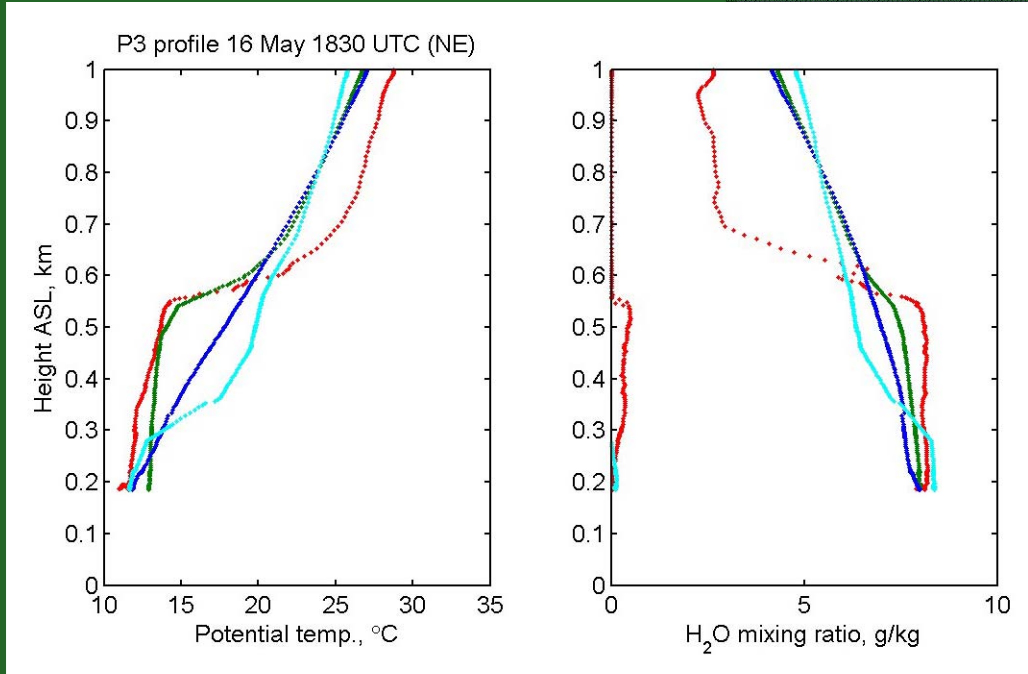
Obs have ~550 m roughly well-mixed cloudy BL with strong, sharp inversion and dry layer above

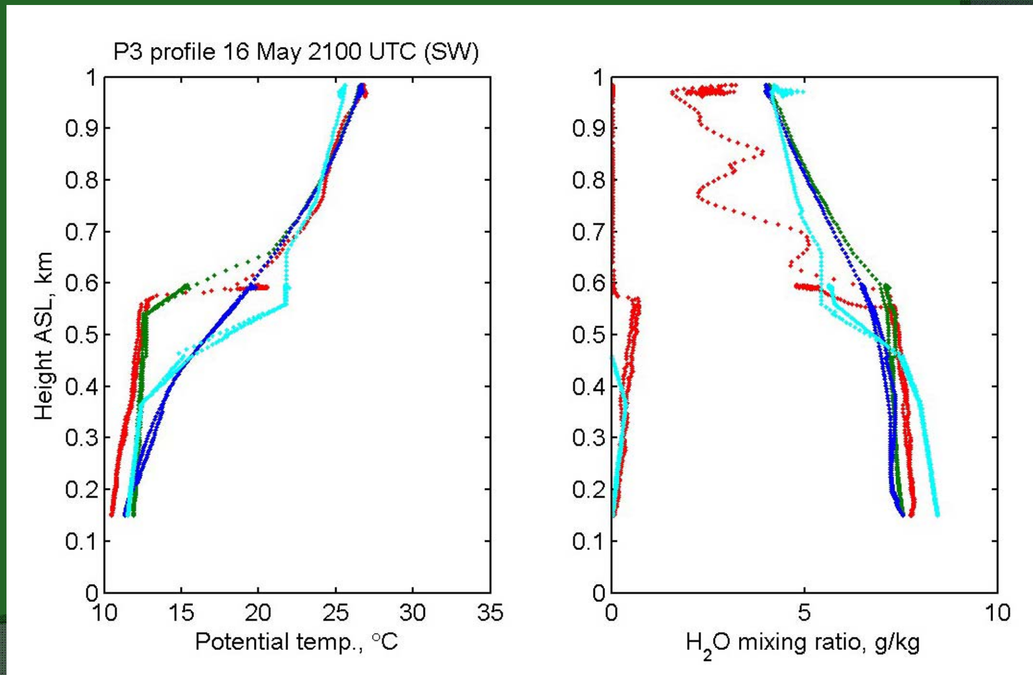
REF has shallow, stable BL
No cloud water because profile is unsaturated

TEMF BL matches obs well
Not saturated at grid scale

COAMPS has shallow BL with good temp and moisture

Red = P3 obs
Blue = WRF REF
Green = TEMF
Cyan = COAMPS



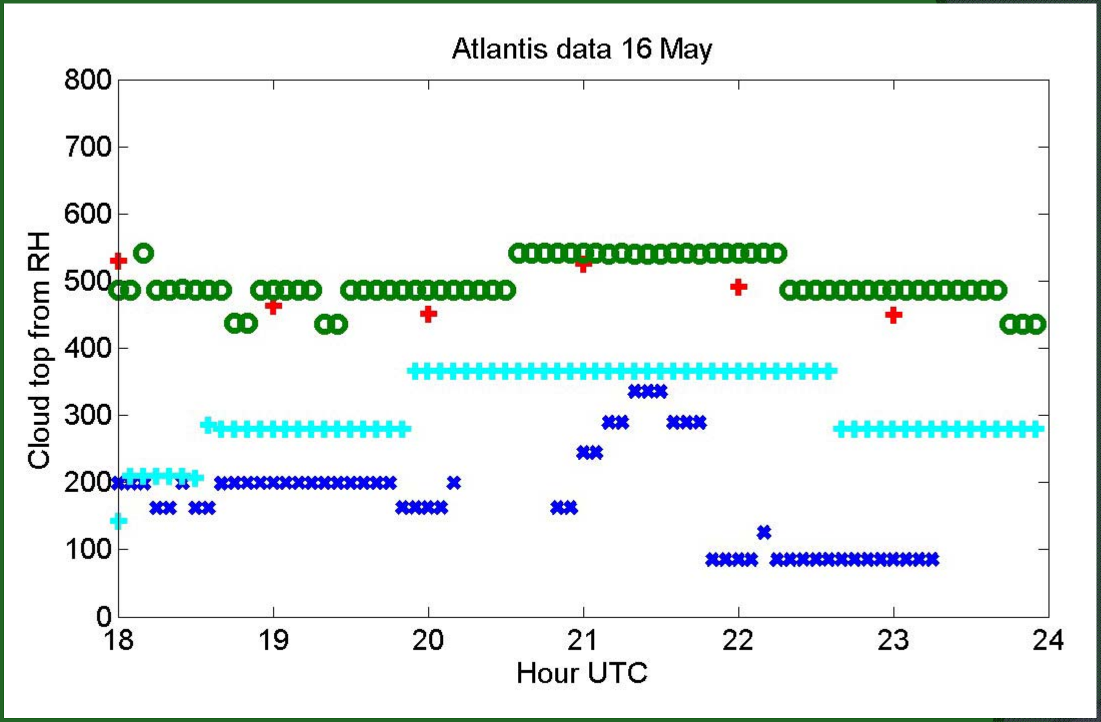


Cloud top along ship track (ERA)

Red = measured
Green = TEMF
Blue = REF
Cyan = COAMPS

TEMF tops good

REF & COAMPS too low

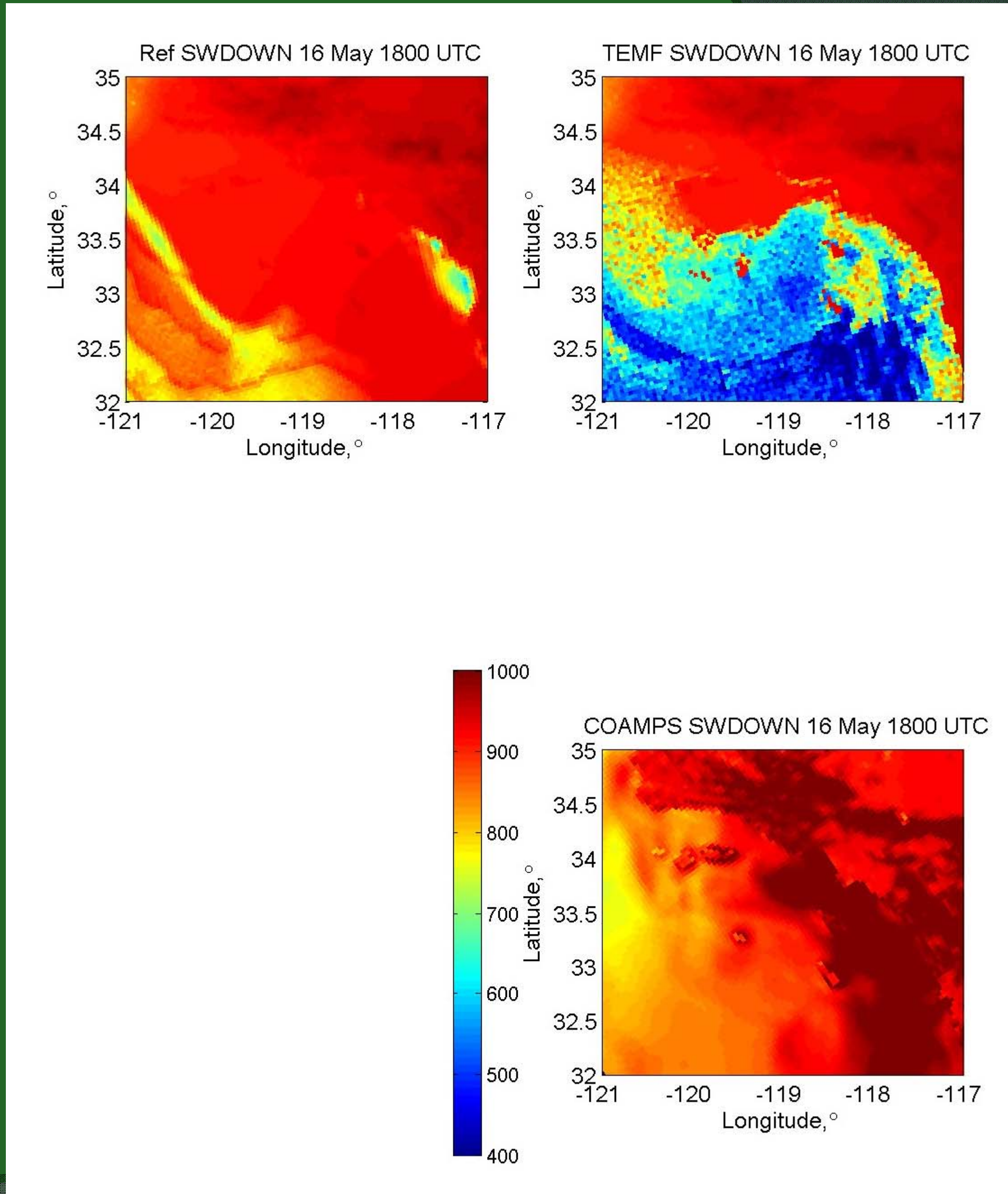


Incoming shortwave radiation (ERA)

Affected by cloud liquid

TEMF has least SWDOWN but maybe still too much (see ship data)
-- formulation still experimental

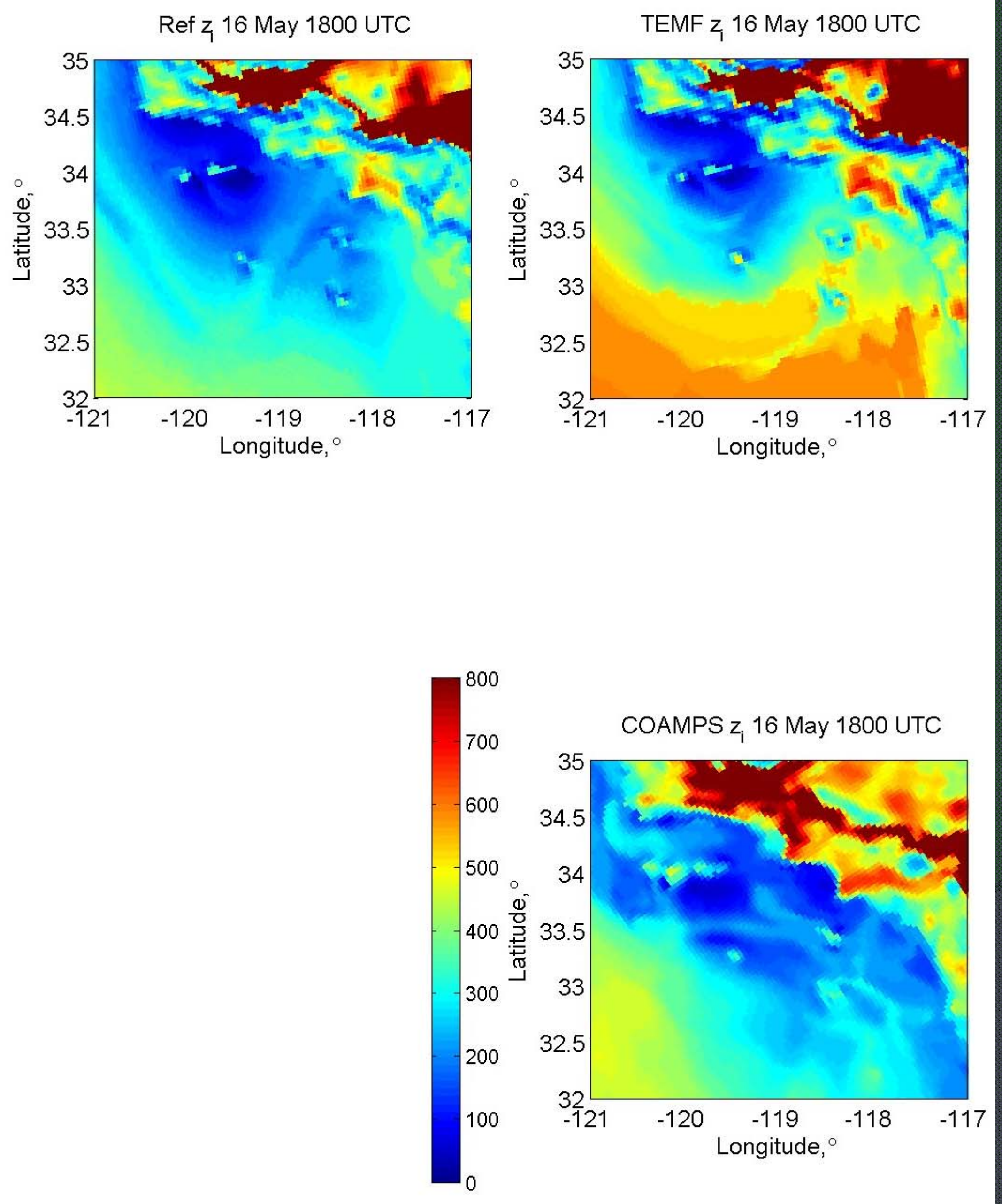
(SWDOWN does not influence SST)



Boundary layer height
(ERA)

REF and COAMPS too shallow

TEMF plausible



Status and plans

- TEMF performance is better than REF (how much?)
- Released in WRF v3.3
- Documented: Angevine et al. (2010) JAMC, release notes
- I'm available for consulting
- Known deficiencies:
  - No ice phase
  - Interface to radiation not in released version
  - Several limits and tweaks for numerical stability
  - Handling of water surface in WRF is crude
- Further evaluation, comparison, and development needed

Thanks to:

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Owen Cooper, NOAA ESRL (satellite pics and surface obs)

NOAA ESRL High-Performance Computing Program

James Cummings, Naval Research Lab (SST data)

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