Characterization of atmospheric stability conditions across different offshore markets and a detailed analysis of the vertical wind shear conditions in Southern New England

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Offshore atmospheric stability: Theoretical considerations

- **Definition:**
  - **Stable:** $T_{\text{air}} > T_{\text{water}}$
  - **Unstable:** $T_{\text{air}} < T_{\text{water}}$

- **Why atmospheric stability matters:**
  
<table>
<thead>
<tr>
<th>Vertical wind shear (In surface layer)</th>
<th>Stable</th>
<th>Unstable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical wind shear (In surface layer)</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>TI</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Wind speed deficit in wake</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Surface Layer</td>
<td>Shallow</td>
<td>Deep</td>
</tr>
<tr>
<td>Limitations of MOST</td>
<td>Significant</td>
<td>no significant</td>
</tr>
</tbody>
</table>

- Site-specific power curve and TI for design
  - [IEC 61400-3-1 (2019)]
  - [IEC 61400-12-1 (2017)]

- Wake decay constant
  - $k_w = \kappa \left[ \ln \left( \frac{h}{z_0} \right) - \psi_m \left( h/L \right) \right]^{-1}$
  - [Peña et al., 2016]

- Vertical extrapolation of wind speed

Offshore stability conditions might not be always similar to the one observed at the North Sea
Atmospheric stability: Theoretical considerations

- Bulk Richardson number ($Ri_b$) for offshore conditions (Grachev and Fairall, 1996).

$$ Ri_b = -\frac{gz(-\Delta \theta + 0.61T_z \Delta q)}{T_z U_z^2} $$

$$ \Delta \theta = T_z 0.0098z - SST $$

$$ \Delta q = q_{sea} - q_z $$

Where:
- $q$ = specific humidity
- $T_z$ = Air temperature at height $z$.
- $U_z$ = Wind speed at height $z$.
- $g$ = gravity acceleration.

- For the $Ri_b$ calculation: $T_z, U_z, SST, P$ and $RH$ measurements.
Case study 0: North Sea

- **Stability conditions at the North Sea**
  - Unstable and near-neutral conditions are prevailing.

Adapted from Sathe et al., 2011
(Only westerly winds were considered)

- **Reanalysis ERA5 (C3S, 201)**

![Map of North Sea with wind conditions](map.png)

1990/01/01 – 2018/12/31

\[ *\Delta \theta = T_z 0.0098z - SST \]
Case study 1: Southern New England

- **Mean synoptic conditions:**
  - Bermuda-Azores high

- **SST:**
  - **Warm sea current:** *Gulf stream*
  - **Cold sea current:** *Labrador current*

  Daniault et al. (2016)
Case study 1: Southern New England

- Mean Atmospheric conditions at Mid Atlantic Bight: ERA5 (1979 to present)

- $\Delta \theta$ Distribution: 1990/01/01 – 2018/12/31

Stable conditions occurs with a larger frequency in Southern New England than in the North Sea

$\Delta \theta = T_z 0.0098z - \text{SST}$
Case study 1: Southern New England

- Atmospheric conditions at Mid Atlantic Bight: In-situ measurements (Air Sea Interaction Tower):
  - **Stable conditions** occurs with a larger frequency than in the North Sea
  - **Unstable conditions** occurs with a smaller frequency than in the North Sea

*Δθ = T_z 0.0098z – SST*

- Positive values of $R_{ib}$ were observed mostly for Southwesterly winds (Mostly summer)
- Negative values of $R_{ib}$ were observed for all wind directions
Case study 1: Southern New England

- Atmospheric conditions at ASIT: Implications
  - Vertical wind shear ($\frac{\Delta U}{\Delta z}$) obtained from LiDAR wind measurements at 60 and 53 mMSL.
Case study 1: Southern New England

- **Atmospheric conditions at ASIT: Implications**
  - Larger occurrence of large vertical wind shears at ASIT compared with North Sea measurements.

**Annual distribution of vertical wind shear**

- **ASIT (LiDAR):** \( \frac{\Delta U_{90-53}}{\Delta z_{90-53}} \)
- **London Array (MetMast):** \( \frac{\Delta U_{88-55}}{\Delta z_{88-55}} \)
- **Greater Gabbard (MetMast):** \( \frac{\Delta U_{88-52}}{\Delta z_{88-52}} \)
- **ASIT (LiDAR):** \( \frac{\Delta U_{90-60}}{\Delta z_{90-60}} \)
- **EPL (LiDAR):** \( \frac{\Delta U_{91-63}}{\Delta z_{91-63}} \)
- **FINO3 (MetMast):** \( \frac{\Delta U_{60-50}}{\Delta z_{60-50}} \)
- **ASIT (LiDAR):** \( \frac{\Delta U_{140-110}}{\Delta z_{140-110}} \)
- **MMIJ (LiDAR):** \( \frac{\Delta U_{140-115}}{\Delta z_{140-115}} \)
Case studies 2 and 3 are based only on ERA5 data

Mean synoptic conditions
1979 - present

\[ \Delta \theta = T_z 0.0098z - SST \]
Case study 2: Japan

- Atmospheric conditions (from ERA5)

Unstable conditions occur with a larger frequency in Japan than in the North Sea.

*Δθ = T_2 \cdot 0.0098z - SST*
Case study 3: Taiwan

- Atmospheric conditions (from ERA5)

Unstable conditions occur with a larger frequency in Taiwan than in the North Sea.
Conclusions

- Stable conditions and large vertical wind shears in Southern New England occur with a larger frequency than in the North Sea.

- Based on ERA5 data, unstable conditions in the west coast of Taiwan and Japan occur with a larger frequency than in the North Sea.

- Offshore atmospheric stability are worth to be analyzed at a regional scale.

- It is important to consider the impact of the atmospheric stability conditions in terms of:
  - Turbulence intensity and Wind shear.
  - Wind turbine performance.
  - Wake losses.
References


- C3S. 2017 ERA5. Fifth generation ECMWF atmospheric reanalyses of the global climate. ERA5 monthly averaged data on single levels from 1979 to present. Copernicus Climate Change Service Climate Data Store (CDS), date of access. https://cds.climate.copernicus.eu/cdsapp#!/home


